Electrical Engineering

May
1941

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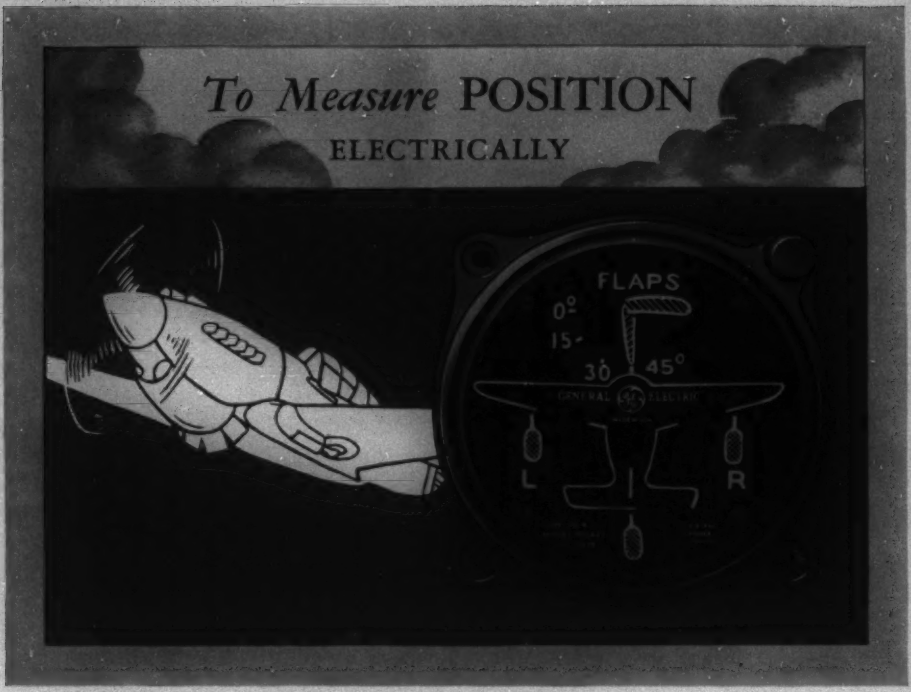
To Measure POSITION ELECTRICALLY



Happy landings—with G-E instruments

WHEN driving your automobile through tight quarters haven't you often stretched your neck to see just how much clearance your fenders had? But think of a pilot—about to land a modern plane—who can't see his retractable landing gear! He has to know if the wheels are down and the wing flaps are in the correct position.

Although the pilot can't see these parts of the plane, he has a means of *knowing* their position at all times. The electric instrument shown above tells him exactly the position of wheels and wing flaps. Without this visual indication he could only hope that the mechanism had operated properly.

The operation of this instrument, developed by G-E engineers for this specific purpose, is very simple. Small, lightweight, d-c Selsyns connected to the wheels and flaps transmit their movement directly to the instrument. The pictorial indication on the dial gives the position of the three wheels and both flaps at a single glance.

Aircraft instruments require no greater accuracy nor positive operation than do the many other instruments General Electric makes for such common but all-important measurements as motor current, voltage, power-factor, frequency, resistance, etc. While these more common instruments do not have such romantic appeal as do aircraft and other special instruments, industry depends none the less upon their accuracy and performance to maintain plant equipment at peak efficiency.

When you need electric instruments for any purpose, may we help you? General Electric, Schenectady, N. Y.

HEADQUARTERS FOR ELECTRICAL MEASUREMENT

GENERAL ELECTRIC

60Z-22-6200

Don't slow up your winders with springy wire.
Eliminate hard copper with this accurate test

THE SOFTNESS TEST is one of several Belden routine production tests which assures that all wire is "dead soft"

Winding a test sample of enameled wire on mandrel of Belden Softness Tester

Adjusting sample of enameled wire to zero point before releasing for test

HOW THE SOFTNESS TEST REJECTS SPRINGY WIRE

For the first time in the history of copper wire testing, a simple and accurate method is now available to all magnet wire users to test the softness of bare, enameled, and textile-insulated magnet wires.

The Belden Softness Tester, developed by Belden engineers, will test the softness of copper wires from No. 14 to No. 30 A.W.G., by giving a direct reading of angular recoil for test coils of 3 to 5 turns. The softer the wire, the smaller the angle of recoil.

Reading on indexed dial, after release of test sample, shows softness of copper wire without further calculation

The wire to be tested is removed directly from the spool without reverse bends. A test length is cut off and one end hooked into a small hole in the mandrel opposite the zero point of the scale. A standard weight is attached to the lower end of the test sample.

Three to five turns (depending upon the size of wire) are layer-wound on the mandrel under tension of the suspended weight. The weight is then cut off and the wire bent back at the cut-off point to form an indicator. The tightly wound coil is permitted to unwind slowly until it comes to rest. The recoil angle is indicated on the calibrated scale. This reading is compared with a standard table. The softness of any wire can thus be determined in a few moments. Hard wire is quickly detected and rejected.

Softness is a primary requirement of good enameled wire. Unless magnet wire is "dead soft," its springiness causes trouble in the winding and forming of coils . . . In Balanced Insulation, softness is not sacrificed for other essential characteristics.

• • •

BALANCED INSULATION

Softness of the conductor may not appear to be closely related to "balanced" insulation.

While the essential qualities of Balanced Insulation are (1) ability of insulation to resist abrasion; (2) flexibility; (3) adherence to conductor; (4) ability to withstand varnish solvents; (5) good aging quality; (6) uniformity of insulation thickness . . . the value of these essential qualities is lost if the wire is not "dead soft."

In making Beldenamel magnet wire, special processes assure that every foot of conductor is dead soft. Therefore, Belden wire users enjoy the combination of Balanced Insulation on "dead soft" wire . . . a combination that reduces over-all winding costs. It pays to use Belden wire on all winding jobs.

Checking temperatures of annealing ovens in Belden wire mill

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Further data on tests and instruments for rating characteristics of *Balanced* insulation sent on request.

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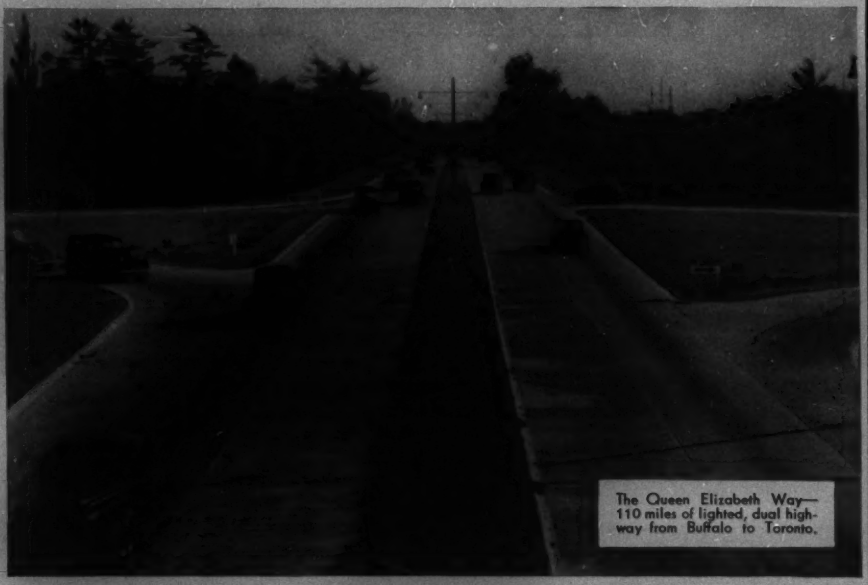

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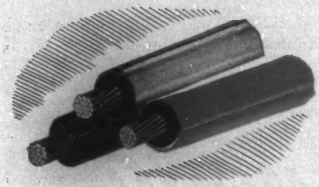

. . . worth planning for

Okoprene-sheathed insulated wires and cables — braidless, with a bonded sheath of **neoprene** vulcanized to the rubber insulation — provide superior protection against sunlight, ozone, chemicals, moisture and oil. They have eliminated corona-cutting and ozone generating as sources of trouble. They are easy to splice and simple to install.

All of these qualities have made Okoprene-protected wires and cables increasingly desirable to industry and now they are also essential to Defense. These, together with other Defense uses of neoprene, have resulted in a temporary rationing of this important synthetic. (Temporary, because increased production facilities now being installed will soon make available a vastly increased supply of neoprene.)

Since this has limited our production of Okoprene cables, it is necessary for us to ask you to make your plans a little further ahead . . . to place your orders as far in advance as possible and to consult more freely with our Engineering Service Department regarding the construction and type of cable which will serve you best.

The many advantages which Okoprene protection offers for many kinds of installations make these outstanding wires and cables well worth planning for.

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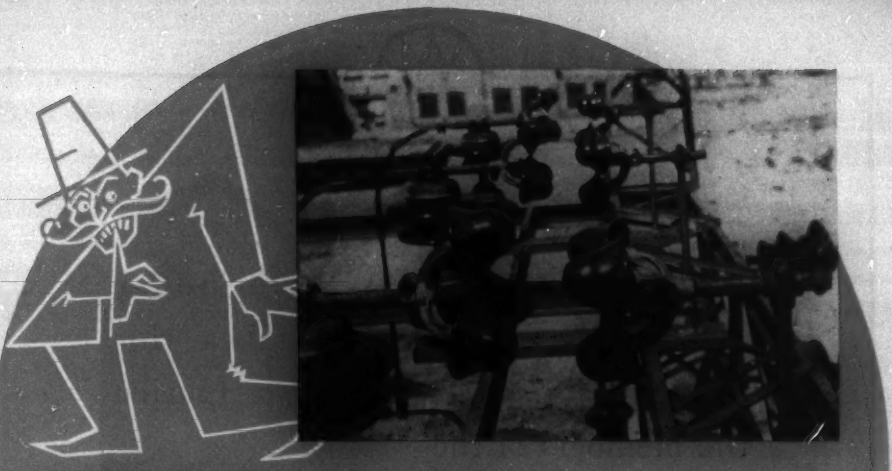

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American Institute of Electrical Engineers

on the occasion of their 1941 Annual Summer Convention at the Royal York Hotel, Toronto, Ontario, June 16–20.

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the New Technique in Testing Electrical Insulation

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In Bulletin 1660-EE we discuss the very important characteristic of electrical insulation, known as *Dielectric Absorption*, and how measurements of it are being made with our Motor-Driven "Megger" Sets.

Insulation resistance tests are made with direct current applied steadily and continuously for 10 to 30 minutes. By this method (especially when tests are repeated at more than one voltage) much is being learned about the condition of insulation in large generators and other electrical equipment. This new and *non-destructive* procedure is an advance in the art of insulation testing.

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For those who do not have large generators or long cables to maintain, but who desire to get the most out of their "Megger" instruments in testing other types of equipment, we have written Bulletin 1655-EE having the above title. Write for a copy.

Your copy of Bulletin 1660-EE, which includes also a description of our Motor-Driven "Megger" Sets, will be sent promptly upon request.

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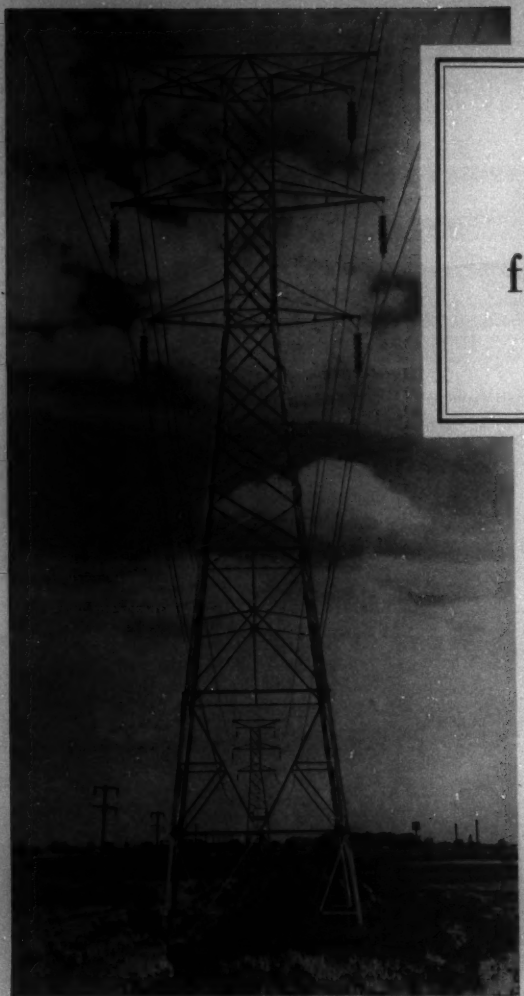

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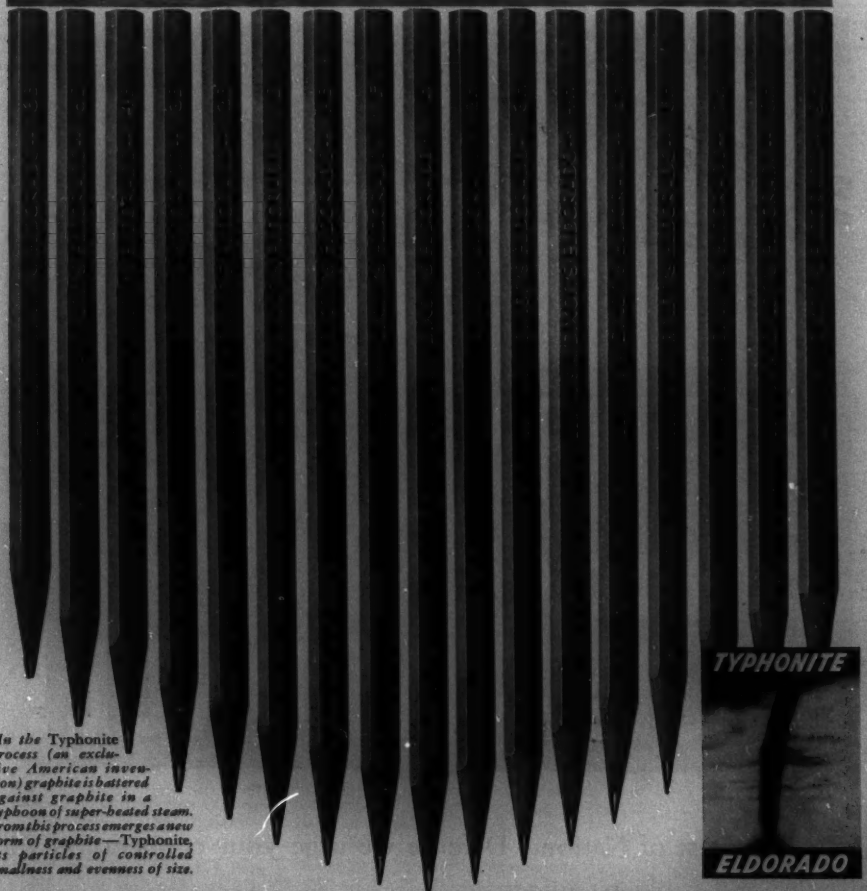

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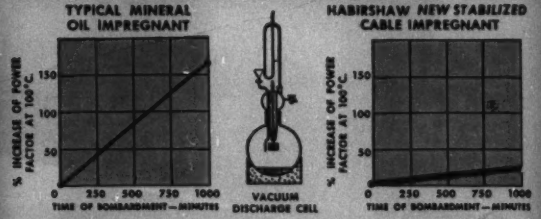

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Electrical Engineering

Registered U. S. Patent Office

for May 1941—

The Cover: Four 25,000-kva vertical-shaft outdoor synchronous condensers at the Toronto-Leaside transformer station. An inspection trip to this station is being scheduled on the program of the AIEE 1941 summer convention to be held in Toronto, June 16–20

Photo courtesy Hydro-Electric Power Commission of Ontario

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¶ Correspondence is invited on all controversial matters.

High Lights • •

Air Circuit Breakers. An air circuit breaker of the 5,000-volt class has been developed which can be applied to circuits capable of producing short-circuit duties of 250,000 kva; this has been made possible through magnetically enhanced diffusion of ionized particles, establishing dielectric strength in a gaseous region which was previously highly conducting (*Transactions pages 197–201*). A 138-kv 1,500,000-kva air-blast circuit breaker recently developed features a new interrupting device utilizing an axial-blast nozzle together with a "conserved pressure" chamber, enabling the interruption of circuits of high voltage (*Transactions pages 193-7*). Application of the theory of interruption with compressed air to an interrupting element suitable for high-voltage work has been made also in connection with the experimental development of an outdoor circuit breaker for 138-kv service (*Transactions pages 217–22*).

Damping in Synchronous Machines. Relatively simple formulas for the calculation of the positive and negative damping torques of synchronous machines have been developed from a simple physical explanation of the phenomena. Using these formulas, the influence of the two axes of the machine upon the damping can be found (*Transactions pages 210–13*).

Designing Cable for Stability. Maximum power-factor stability of cable insulation under load-cycle conditions so far attained has been achieved by the combination of a new principle of cable structure and a newly developed impregnant having a marked degree of stability (*Transactions pages 206–10*).

Control in Interconnected Systems. To co-ordinate the operations of interconnected power systems of any size or geographical extent, automatic frequency controllers with time-error correction and tie-line controllers with frequency bias and time-error correction have been developed. The principle of frequency bias on a tie-line controller has been used extensively to permit maximum deviation from schedule load with minimum change in generation (*Transactions pages 232–6*).

Complacent Confusion. Since our democracy rests full-weight upon the proposition that the people are competent to determine their destiny, the consequences of confusion are not only personally but nationally disastrous, declares an eminent educator and engineer, who urges as a remedy for the prevalent state of complacent confusion that students learn to take the initiative in their own education (*pages 199–201*).

Magnetic Fields in Meters. As part of a general study of magnetic conditions existing in watt-hour meters during their operation, the effect of wave form on the registration of such meters has been studied under carefully controlled conditions (*Transactions pages 202–05*).

Network Master Relay. A three-phase single-element induction-cylinder network master relay which uses potential coils connected from line to line has been found to produce greater tripping torque during unbalanced primary feeder faults than did previous relays, which were three-phase, three-element devices with line-to-neutral potential coils (*Transactions pages 237–41*).

Protective Link. A protective device in transformers has been developed which disconnects any unit on which a breakdown or fault occurs internally, thereby reducing the shock to or outage on the feeder. The "protective link" consists of a fusible element within a fiber tube having one fixed and one movable electrode (*Transactions pages 226–9*).

Lamp Starter. Successful operation of hot-cathode fluorescent lamps is dependent upon a satisfactory starting device. The glow switch, a small simple, two-wire thermal relay operated by the heat from a glow discharge, performs automatically the necessary functions, and also is finding application in relay circuits (*Transactions pages 223–6*).

Directional Relay. An inductor-loop type of construction for high-speed polyphase directional relays, believed to offer decided advantages over other types, has been developed. Such a polyphase relay can be used for directional discrimination with high-speed impedance or overcurrent relays, and also for pilot-wire service or with carrier-current systems (*Transactions pages 246–8*).

Static Electricity. Lack of understanding of the generation of static electricity on rubber-tired vehicles has been responsible for the slow progress in development of effective precautionary measures against its hazards; analysis of the nature of the problem shows why existing methods of control are largely ineffectual (*pages 202–08*).

Resistance Welders. Factory wiring for resistance-welding machines has been considered in the third section of the report of the AIEE welding committee's subcommittee on power supply for welding operations, which shows how properly to lay out a plant distribution system for serving welders (*Transactions pages 185–92*).

Temperature Variations. Curves showing the variations of mean temperatures with altitude throughout the United States have been developed as an aid to the Institute's standardization activities (*Transactions pages 230–2*).

Measuring Cloud Heights. A "ceiling projector" is used to learn the height of the cloud ceiling over airports at night; a photoelectric device has been developed to extend its use to daytime hours (*pages 209–10*).

Electric Power in Aircraft. Because the makers of electrical equipment have taken little interest in the special problems of the aviation industry, other types of accessory power have been used for duties which electric power could easily perform; some of the problems and needs are presented for consideration (*pages 218–25*).

Small-Diameter Wires. Among significant features of the 1940 National Electrical Code are the recognition of small-diameter wires and permission to use these wires to fill a greater percentage of conduit area; these and other changes in the wiring tables have been analyzed (*pages 211–16*).

Switching Surge Voltages. Current-limiting fuses have been designed to provide inherent control of switching surge voltages with designated acceptable limits; these fuses employ conducting elements having two or more sections of different diameters (*Transactions pages 214–17*).

Ultrahigh-Speed Reclosures. Conclusions regarding ultrahigh-speed reclosing of high-voltage transmission lines have been developed on the basis of data covering five years' operating experience with 33 installations of high-speed reclosing equipment (*Transactions pages 241–6*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication are: a symposium on fluorescent lighting by O. P. Cleaver (A'36), Preston Millar (M'13), A. B. O'Day, and Arthur A. Brainerd; an article describing the calculation of fault currents in industrial plants by R. C. R. Schulze; a report on apparatus bushings by the AIEE joint committee on bushings; a paper on bushing and associated insulation testing by the power-factor method by C. C. Baltzly (M'23) and E. L. Schlottere; a paper on high-voltage bushings designed to meet modern service by T. F. Brandt (M'37) and H. L. Rorden (M'36); a paper on enclosed busbar electrical distribution systems for industrial plants by E. T. Carlson (A'35); a paper outlining a construction theorem for evaluating operational expressions having a finite number of different roots by P. C. Cromwell (A'28); a paper reporting a study of sound-levels of transformers by H. Fahnoe (A'35); a paper on an electrolytic process of scale removal from steel by H. W. Neblett (M'21); a paper on the suppression of magnetic vibration and noise of two-pole turbine generators by A. L. Penniman, Jr. (M'32) and H. D. Taylor (M'34); a paper on arc-backs in ignitrons in series by J. Slepian (F'27) and W. E. Pakala (A'38); a paper reporting experience with preventive lightning protection on transmission lines by S. K. Waldorf (M'36); a paper on the detection of initial failure in high-voltage insulation by J. B. Whitehead (F'12) and M. R. Shaw, Jr. (A'40); a paper on lead storage batteries in the transportation field by Roland Whitehurst (M'21); and a paper dealing with surges on Chicago 12-kv system by F. O. Wollaston (A'27) and H. J. Plumley (A'39).

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Complacency in Confusion

ROBERT E. DOHERTY
FELLOW AIEE

Because it contains so much food for thought for all students, whether in college or out, this address, originally delivered to a student group at the institution of which Doctor Doherty is president, is presented here for the benefit of all "students" in the AIEE audience

MOST PEOPLE live in a state of complacent confusion. College students and graduates are no exceptions. How many of them, for instance, have only a vague and confused notion of the fundamental principles of their professional study or practice; how many of them are content to live without a clearly thought-out philosophy of life; how many of them are inclined to think with their emotions instead of with their minds; how many, disillusioned by events of the past decade, are intellectually lost and assume the role of the cynic; how many, I ask, thus bear their own evidence of confusion? I believe you will agree with me that the number is discouragingly great.

The consequences of complacent confusion are serious. If these consequences were personal only—if they were merely the unrewarded personal careers, or the travail of minds that see no way out of new and trying situations, or the sterile satisfactions that go with intellectual poverty—they would be serious enough. But the consequences do not end there. They become national in scope when confused minds decide matters of destiny, for our democracy rests full-weight upon the proposition that the people are competent to determine their destiny. If they depend upon leadership, as they must, and leadership is confused, the consequences in national and local community life must be devastating, and indeed they have been devastating. By leadership I do not mean Federal leadership alone. It is only a part of the whole. I mean every policy-making body or policy-making person in the country, whether in business, industry, education, or government. The general direction of flow of national and community life depends upon the general policy pattern constituted of all the individual policies of these agencies, and the people must accept that flow of life. Hence the consequences of confusion may strike you on two serious counts. They may strike you personally and professionally if you elect to join the large ranks of the confused, and then you may continue to be the victims with all the rest of us of confused leadership.

You thus have a definite and direct personal interest in this matter, and also a very important interest as a citizen, even if this may appear to you less direct. My purpose here is to help you to recognize your interest and to encourage you to do something about it. I realize that the immediate, direct personal interest is, from your point of view, probably a more convincing basis for my appeal to you, but since the general social interest is not less important to you, I wish to pursue it further.

In the confused and demoralized world in which we now live, and which certainly will become more confused and more demoralized, there is a great challenge to the college students of America. It is the challenge to become intellectually prepared to deal with such a world, to meet with intelligence, courage, and confidence the new and trying situations which rapid changes are now bringing about. In such a world, which will be the world of your generation, life in America must be profoundly affected. National life will be difficult. Individual life will be difficult. The formulas of day-to-day contemporary life will not suffice because many of them will not apply to the new situations. New formulas must be thought out, and in this thinking there must be a return to the very fundamentals of science and living. There must be a clarification of basic philosophies—personal, professional, social. There must be clear, straight thinking. And to have these there must be genuinely educated people. Walking encyclopedias and handbooks will accomplish little. College graduates who have learned only the routine skills and formulas of their work will be intellectually lost in a world of new problems and thus will be ineffective in determining either social or individual destiny. There must be an intellectual renaissance, and that is your challenge.

I have mentioned confusion and its consequences and how I find these related to your own interests. I wish now to consider the question why in a nation of incomparably great educational opportunity there should be such pervasive confusion; why it is that the experience of 16 or 18 years of formal study, especially the period of college study, does not cultivate in more students a deeper understanding and a greater intellectual competence? After I have considered this question, I shall indicate more fully the nature of the task you will face if you set out in earnest to cultivate your own mind to its full capacity.

An address delivered to students at the Carnegie Institute of Technology, Pittsburgh, Pa., on "Carnegie Day," November 26, 1940.

ROBERT E. DOHERTY is president of Carnegie Institute of Technology, Pittsburgh, Pa.

Does the habit of confusion and superficiality among so many college graduates stem from an inherent lack of intellectual capacity? Many times I have heard this given as the reason. But my personal experience with students and large numbers of young graduates does not confirm this defeatist view. Now I know it is a long hard struggle for most of us really to learn the art of constructive thought, but I know too that many of us have more capacity for understanding and for intelligent thought than we are given credit for having. In college we may be slow in getting our thinking gears into mesh; and if while we are trying to get them into mesh the external machinery of classroom procedure moves too fast, the gears get stripped. Then disorder and confusion result. However, with a little more patience and a little more emphasis at the right points, more of us might have got our mental machinery into gear and successfully made the shifts until we got into high gear. No, I do not accept the view that inherent limitations of mind fix the intellectual achievements of college graduates at their present levels. We all have our own limits, of course, and these are not the same for everybody; but I am convinced that there is still good leeway between actual and potential intellectual achievement. So we must look elsewhere for the trouble.

I have already hinted at it. We strip the gears. The trouble is that too much is undertaken in the time available. In the modern curriculum there is so much subject matter to be covered that in the time available few, if any, students can cover all of it with understanding. The result is that they do not understand much of what they have covered, or only partly understand it. They come to depending more and more upon memorizing, and less and less upon understanding. This process of racing through, with one eye on the next quiz, pages of words and formulas with half understanding or no understanding is utterly demoralizing. It is repeated in American colleges day after day, month after month, year after year, until superficiality becomes a habit, until confusion becomes accepted as a normal state of mind. With such a habit firmly established in college, it naturally persists afterward; and thus confusion and superficiality mark the minds of too many graduates.

It is therefore a deplorable fact that the college diploma is usually not a certificate of a cultivated mind. Rather it may signify only that the graduate has acquired the requisite number of credits by meeting the course requirements of grades, lessons, and attendance. And the meeting of these requirements is no guarantee of intellectual competence in the sense that I am stressing. The work may have been fully done and good grades received, and still the diploma might not be a certificate of a cultivated mind. I mean a mind that can cope with new situations—a mind that intelligently can find its way out of perplexities, whether these be professional, personal, or social—and that has the capacity of humane appreciation. The test for identifying a cultivated mind is to face it with perplexities—to face it with new situations not in the books but involving principles and knowledge which that mind has studied. Then see how it behaves. Does it grab for straws, does it become emotional, is it evasive, does it give up? Or does it try to anchor to principle, does it have a philosophical base for its thought, has it essential knowledge, however limited, that will give meaning to its principles and to its philosophy, and can it think logically in applying all of these to the understanding and solution of the new situations with which it is faced? I might state the point in still different words. An educated person is one whose intellect has been cultivated in the processes of understanding, of thinking, of appreciating, of solving perplexities; and the only way yet found that I know of to cultivate these processes is actually to engage in them, to experience them, and to keep on experiencing them at increasing levels of difficulty. Thus, the question whether at commencement you, and indeed all other college graduates, will have achieved the status of educated persons will not, I am afraid, be answered completely by the fact that you and they have received diplomas. Moreover, neither will the extent to which you have approached that status be necessarily measured by the number of courses you have taken, nor yet infallibly indicated by our grades. But you can measure it. You can tell whether you understand thoroughly what you have studied, whether you have grasped great truths and worked them into your thinking so that as time goes by you can think your way out of situations and problems of increasing difficulty. You can know your own mind. Do not rest upon the assumption that a college diploma tells the whole story. It does signify that you have completed a college program and it may also be a ticket to a job; but it is not a ticket to the ranks of intellectual competence or to a successful career.

I am trying to have you grasp what I consider to be the most important thought in your educational career. It is this: that genuine education—the only kind of education that will help you to advance professionally and that will help you to live a life of service and satisfaction in a changing world—is not to be achieved merely by memorizing large quantities of miscellaneous information; it is not to be achieved merely by learning formulas, important as many of these may be; still less is it to be achieved by memorizing the words or the symbolisms of such information without understanding what they mean. It is to be achieved only by the acquisition of fundamental knowledge that is thoroughly understood and by the development of a purposeful attitude of mind and of a competence in thinking your way out of perplexities.

I realize I am on delicate ground. I run the danger of suffering your judgment that I indulge in pedantic counsel to you, and the faculty's judgment that my appraisal may be too pessimistic. I hope that I may not deserve such judgments; but if I seem to, may I ask that before the judgment becomes final, you at least think over carefully what I say and place it against the background of the world changes you see on all sides.

In any case, do not misunderstand me. Memorized information and formulas are of course important, indeed they are essential, but only so if they are thoroughly understood and furthermore are related *in your own mind* to a definite intellectual purpose. Then they cease to be miscellaneous information and become knowledge. For instance, it is futile to learn, however perfectly, the language

of Newton's laws of motion unless the significance of the language is clearly comprehended in its relation to the tangible physical facts which these laws correlate; in other words, unless one can visualize and interpret a physical situation involving these laws.

Let me be more specific regarding the nature of genuine education as I conceive it. I will discuss four essential elements which I have already mentioned in passing. The first is the acquisition of fundamental knowledge; that is to say, the learning and understanding of great basic truths and of a sufficient background of related fact to give definite and constructive meaning to those truths. As great truths I include those in the physical world, in the social and economic world, and in the realm of the human spirit. There are not many. I refer to such principles as the law of conservation of energy; the law of diminishing return, the principle underlying the golden rule. There are of course hundreds, perhaps thousands, of principles and formulas derived from such basic truths, much as the numerous theorems of geometry are derived from a few fundamental premises; and then there are perhaps a few hundred more based upon somebody's opinion. But it would be both hopeless and futile to undertake to learn all of them. One must discriminate between these and the great truths that form the bedrock of intelligent thought.

A second element is the development of a philosophy of life. This is a long process. It is settling upon basic purposes and attitudes in life and the reasons for them; it is placing the indispensable underpinnings of faith and courage and self-confidence. It is a continuing building process—the process of testing against the experience of your own life and the recorded lives of others, those purposes and attitudes that are tentatively adopted and of thus selecting and fitting in, piece by piece, the structural units of a life purpose. For instance, one important and immediate unit in this structure with which you are now presumably concerned is professional purpose. I do not mean the specific details and place of your future work, but the broad lines of professional activity that now seem to offer the greatest promise of those satisfactions which, after careful thought, you have come to cherish.

Next I mention humane appreciation. A mind or life that shuts itself off from an understanding of man as a human being; that shuts itself off from an appreciation of the desires and disappointments, the yearnings and satisfactions that motivate human activity; that shuts itself off from an appreciation of the literature and arts through which the human soul has attempted to express itself—such an isolated mind or life is only half human, and therefore not genuinely educated.

Finally I come to intellectual competence. Without this competence the other elements I have mentioned—fundamental knowledge, a philosophy of life, and humane appreciation—would represent merely passive satisfactions. Such satisfactions are of course important fruits of education. But they do not constitute a whole; they are complementary to another fruit—the fruit of constructive thought. And to achieve this competence in thinking one's way out of perplexing situations is to round out that genuine education which I am urging upon you.

Do you want that kind of an education? Do you wish to prepare for keen competition? Do you wish to preserve your precious liberty of thought, speech, and worship?

If you want these things you can have them, provided you pay the price. I doubt that the price is any higher than you are now paying, for I know most of you are already working hard. But it is a different kind of price. It is the price of *taking the initiative* in your educational work. This demands of you greater resolution than does merely *following* the regimen of classwork. It requires greater devotion to purpose.

No one can possibly do this educational *job* for you. The assumption that the instructor can do it for you is the basis for more educational confusion than any other I can think of, save one, namely, the assumption that education is achieved by memorizing a lesson merely in order to report it back on a quiz and get a grade. A recent definition, if I may be facetious, is that education is the process by which the instructor's notes get into the notes of the student without passing through the brains of either. No, the kind of education I am proposing cannot be given to you; you must *win* it by hard intellectual struggle in which you take the initiative. The faculty may inspire you to intellectual effort, but you must exert it; the faculty can help you to understand, but you have to do the understanding; the faculty can coach you in the art of logical thought, but you must do the thinking; and the faculty can help you to cultivate good taste and humane appreciation, but you have to do the cultivating. Every time you struggle with a new concept and *master it*—for instance, a physical law, or an economic theory, or a concept of art—you will have made an educational advance, you will have added to your intellectual stature. Furthermore, every time you make *use* of such a law or theory or concept to think your way out of a perplexity or to experience a new appreciation, you will have achieved another and further intellectual advance. But in both cases you must do the job. You, not the coach, must carry the ball.

So I urge you to take the initiative and learn to use your heads. In the first place, dig yourself out of confusion. Insist on understanding! Do away with superficiality! Stop memorizing words and formulas that you do not understand, merely for a grade. Do not go on cultivating a habit that will cripple your mind for the rest of your days—the habit of superficiality, the habit of accepting confusion as a normal state of mind, the habit of playing on words that carry no meaning. You know when you understand and when you do not; when you grasp a point that is clear and clean cut and when, instead, it is blurred and confused. With all the emphasis in me I repeat: Insist on understanding! Then, under the guidance of the faculty in your regular class programs, but under your own initiative, you will be in position to go forward more effectively and more rapidly with the acquisition of great truths, the evolution of a philosophy of life, the cultivation of humane appreciation, and the development of intellectual competence—in other words, a genuine education gauged to the demands of the changing world in which you will live.

Static Electricity on Rubber-Tired Vehicles

ROBIN BEACH
FELLOW AIEE

Although the public is becoming increasingly conscious of the fire and explosion hazards presented by static electricity, development of precautionary measures has been seriously impeded by lack of understanding of the nature of the problem. This study of the fundamental elements of static electricity on rubber-tired vehicles is intended to provide a basis for developing methods of control.

STATIC electricity received scant attention from the layman until the use of radio receivers became widespread a few years ago. Although atmospheric and man-made interference with radio communications produced many difficult and interesting problems for the radio engineer, it was, and still is, just a nuisance to the general run of broadcast listeners.

The public, however, is more static-conscious today than ever before. This is due, no doubt, to the frequent, almost daily press reports of disastrous fires and explosions attributed to discharges of static electricity, in grain elevators, oil refineries, munition plants, paint factories, and other industrial operations. News items of explosions "caused by static" in motion-picture projection booths, hospital operating rooms, domestic kitchens, and gas-filled basements of school houses vividly emphasize and bring home the subject of static electricity to the newspaper reader.

Rapid and extensive developments in industrial processes and equipment, coupled with the fact that so little really is known about the generation of static electricity and the vagaries of its behavior, seem to account for the alarming increase in the number of industrial fires and explosions presumably and probably caused by it.

The voltages which result from rapidly moving belts, conveyors, paper stock, fabrics, and similar materials, as well as those which originate at nozzles from rapidly issuing steam and other gases, attain amazingly high values under favorable conditions. It is not generally known that charges of electricity are produced under conditions of violent turbulence and high velocity, when liquids, such as petroleum and its fractions—gasoline, naphtha, kerosene, and others, are pumped through pipe lines, and that the accumulation of these charges at the terminal tanks under certain conditions can cause high voltages to be developed.

In these various ways, voltages ranging from a few thousand up to as high as 75,000 volts have been recorded, in some cases with large quantities of stored charge ready to arc to ground.

Surprising as it may seem, one can generate a stored charge in his body at a voltage as high as 10,000 volts by scuffing over a woolen rug on a dry, cold day and, upon discharge, cause a spark of sufficient intensity to light a cigarette lighter or a gas jet. Even this commonly known phenomenon can be potentially dangerous. Recent newspaper accounts described the ignition of vapors from anesthetics being administered to patients on the operating table, causing the patients' deaths. The vapors were ignited by the discharge of body charges of the surgeons generated by their scuffing about on the rubber floor mats during the operation.

From a humane point of view alone, tragic accidents of this sort call for a widespread and concentrated study of the generation, behavior, and control of static electricity. The wasteful costs of litigations arising from such accidents and the losses occasioned by the destruction or damage of properties constitute an economic and engineering problem of importance.

HAZARDS OF STATIC ELECTRICITY ON RUBBER-TIRED VEHICLES

A great many fires and explosions are known to have originated from the sparks resulting from high-voltage discharges on gasoline trucks, oil trucks, and carriers of explosives and of other inflammable materials. Fires have occurred at bulk plants and distributing stations of the gasoline and petroleum companies, despite the employment of rather costly protective devices installed in the hope that such devices would discharge all traces of static electricity. Static electricity is an ever-present menace to all industries which manufacture and transport inflammable and explosive commodities. Many people are surprised to learn that an empty gasoline truck, in which the residual vapors are thoroughly admixed with air, is no less of an explosion menace on highways than a load of dynamite. Even the static-electricity shocks from busses and automobiles should not be considered lightly, since, in cases of impaired health, they have been known to lead to serious consequences.

Since the use of rubber-tired vehicles for industrial carriers is being extended into many new fields, the fire and

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explosion hazards from static electricity are being multiplied. Too frequently precautionary measures which should be taken against these dangers are unknown to those employed in these industries. In fact, since practically no authentic information has been published on this subject of static electricity on rubber-tired vehicles, it is problematical where information and advice on the subject could be obtained.

The author was similarly confronted with this dearth of information about two years ago in connection with a court case in which a fire was believed to have been started by the discharge of static electricity from a storage tank that was being filled by a gasoline delivery truck. Since that time he has conducted many tests on pleasure vehicles, busses, trucks, and tank trucks, both on the highways and on the new Otis "proving stands," for the purpose of securing as complete information as possible on the subject.

THE VARIABLE FACTORS IN THE PROBLEM

These tests led into devious and lengthy studies in order to determine where and how the electric charges on the car bodies were generated, what their polarities and distributions were on the tires and on the car bodies, what the magnitudes of the voltages were between the car body and ground, how the characteristics of the roadways affected the problem of generation, how conditions of tire-loading, tractive effort, and temperature influenced the voltage, and how other such variables as humidity, seasons, types of roadways, and tire conditions entered into the general problem. The problem contains many variables, some of which do not lend themselves readily to control unless costly methods are employed. The results of these studies are recorded in this article.

The seat of the generation of electric charges that constitute the electrification of a rubber-tired vehicle is at the area of contact between the tires and the roadway. The process of electrification is identical with the well-known ones of charging ourselves by scuffing on a woolen rug, or of charging a vulcanite rod by rubbing it with a piece of fur. One of the substances acquires charges of positive electricity while the other gains an equal number of charges of negative electricity. Since rubbing is commonly associated with this method of electrifying substances, it is not difficult to understand how the misnomer "frictional electricity" was given to the process many years ago. Actually, friction plays no part in the fundamental nature of electrification of substances brought into intimate contact. The application of pressure or friction between the substances simply helps to establish more extensive and at the same time more intimate contact of one substance with the other. Really there is no such physical phenomenon as frictional electricity.

THE PRINCIPLE OF "CONTACT DIFFERENCE OF POTENTIAL"

This process of electrification is that known as "contact difference of potential". It is a most interesting phenomenon about which much yet remains to be learned. If two substances, say two metals, are placed tightly in contact, a redistribution of so-called "free" electrons takes place within them, and therefore a difference of potential is established across their boundary, which is the contact difference of potential. The substance which gains electrons becomes negatively charged and the other, having lost electrons, becomes positively charged. The boundaries of the metallic substances are normally bombarded by the free electrons in their attempt to escape, a condition that is similar to the boundary restraint imposed by surface tension against the escape of atoms of a fluid. The flow of the electrons between metals in contact occurs from that substance for which the lesser force acts at its boundary contacts to impede their escape.

These contact voltages for metals have been found to range from a few tenths of a volt to about one volt. The surfaces that are firmly in contact are actually separated by distances of the order of molecular proportions, approximating 1/100,000,000 inch or less. These orders of magnitudes are important, since, as we shall see, they determine the values of voltages found in static electrification. As the two metals are now separated, the stretching of the lines of force between the positive charges on one and the negative charges on the other causes the voltage between them to increase, thereby tending to reunite these separated charges. Being free to move through the conductive metal to the location of least potential difference, which occurs at the last point of remaining contact between the surfaces, the two metals upon separation thus completely lose their charges and hence all evidence of former contact voltage.

In nonconductors of electricity, with which we are concerned here, the electrons are unable to move about freely as in the metals. When a vulcanite rod, for example, is

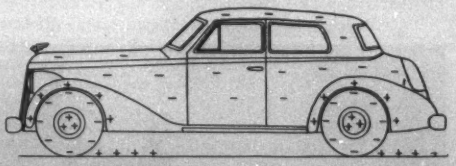


Figure 1. The normal distribution of charges on the body of an electrified vehicle, showing the "wake" of positive charges in the roadway

rubbed with fur, electrons are known to pass from the fur into the vulcanite at each point of contact and remain there fixed in position. The rubbing procedure merely serves to cause new areas to come into contact and to provide additional interchange of electrons, thereby multiplying the amount of electric charge acquired by each surface. The contact voltage is probably somewhat lower than for the metals, but when the separation of their surfaces is made one important difference distinguishes the nonconducting substances from the metals. Since the charges are constrained to remain in fixed positions for nonconducting materials, each substance retains about as many charges as were imparted to it by the contacts, and the difference of potential increases rapidly as the surfaces are separated and in inverse proportion as the capacitance decreases ($C=Q/E$), attaining values of many thousands of

volts. A similar condition is obtained by rubbing a metal with a nonconducting substance, provided the metal is insulated from ground so that it retains its charges.

CHARGING THE VEHICLE

Rubber tires are composed of organic materials which possess excellent insulating characteristics. This is also true of the materials which compose the modern highway, such as macadam, asphalt, concrete, or wood or granite blocks. As the wheels of the vehicles roll along these roadways, the tires acquire electrons and thereby become highly charged with negative electricity. The positive atomic charges lie as "wakes" behind the speeding wheels in the surface of the roadway, and they concern us no longer. However, the negative charges on the tires have a strong influence in electrifying the car body.

The high negative electrification on the tire treads repels to the more remote parts of the car body the free electrons in the metal of those parts that are in closest proximity to the tires, such as the wheels and fenders. This leaves high positive electrification on the adjacent metal parts as so-called "bound" charges; and the repelled electrons on the remainder of the metal parts of the car constitute what are known as "free" charges, because, if a path is provided for them, they will flow off to ground. Figure 1 shows the normal distribution of charges on a car body. This separation of the charges on the car body is the well-known process of "electric" induction. In other words, the charges induced on the metal parts adjacent to the negatively charged tire treads are positive ions because the free electrons are repelled, and these positive charges and the negative charges on the tires are bound by a strong electric field which exists between them—a condition which is measured by their potential difference or the voltage.

If the negative electrification on the tires is assumed to be removed by neutralizing the charges, the "free" charges would no longer be repelled, so they would flow back and neutralize the positive ions, or "bound" charges. The car body would then be again uncharged and no voltage would exist between it and ground. On the other hand, when the car was normally charged by induction from the electrified tires, suppose the "free" charge had been conducted to ground by momentarily connecting the car body to a hydrant, and suppose the negative charges were then neutralized on the tire treads, the positive ions which are fixed in their positions in the metal structure then would be the only charges on the car. They would strongly attract free electrons to neutralize them, thereby leaving positive ions distributed over the entire body. Since these positive charges cannot escape, the car still would have its previous value of potential above ground, only it now would be positive, whereas prior to discharging the "free" negative electrification, the potential was negative with respect to ground. These various conditions were measured and checked, both on road tests and on the Otis proving stand, by voltmeter, by microammeter, and by electroscope—the latter being a device by means of which the presence of a minute amount of charge and its polarity may be determined.

METHODS OF TEST

During the early stages of testing for voltages between car bodies and ground, readings were taken on cars as they came to a standstill at the toll booths at the Holland Tunnel in New York City, and at the Marine Parkway Bridge in Brooklyn. An electrostatic voltmeter was employed for these measurements which had various scales calibrated in volts up to 15,000. The ground terminal of the meter was connected to a grounded stanchion, and the high-potential terminal was connected to a wire which was attached to a contactor on a pole, like a fish pole, that could be touched to the bumpers of cars as they stopped for toll. Figure 2 shows such a view. These readings were taken largely during the summer months. Busses and trucks, and especially heavy gasoline trucks, gave the highest voltage readings, approximating 5,000 volts. As was found later, the voltages at these locations were affected greatly by the high

Figure 2. Cars undergoing the measurement of their electrostatic voltage at the Marine Parkway Bridge, Brooklyn, N. Y.

humidity of the summer season, by the direct exposure to salt atmosphere, by hot tires, by relatively low surface resistivity of the roadway, and by various other factors.

Later the author equipped his automobile as a traveling laboratory for tests on static electricity. A metal contactor was attached to, although insulated from, the front bumper, being located midway between the front wheels, so that it could be lowered to the pavement; and by means of an insulated wire this contactor could be connected to the ground terminal of the electrostatic voltmeter. The high-voltage terminal of the meter likewise could be connected to either of two insulated wires, one from the inner surface of a fender, and the other from the upper part of the car body. During the dry, cold weather, the meter indications were, for the most part, well off the 15,000-volt scale and subsequently a 30,000-volt scale was added to the meter. When the car was stopped at these times, the voltage was found to remain at its high value for the full duration of the stop of 20 minutes or more, sometimes with no apparent decrease, while at other times the indication would very gradually diminish, giving evidence that hours might be required for total discharge.

Figure 3. A Ford sedan being tested for electrostatic voltage on the Otis proving stand at the garage of the Brooklyn Edison Company

Under these conditions the use of the so-called "drag" chain, as frequently seen with two or three links dangling on the pavement at the rear of gasoline trucks, was found to make no measurable difference in the rate of decrease of the voltage on the car. For such tests, a set of two skid chains was attached to the bumpers so as to provide extensive contact with the roadway between the wheels. Since the pavement was not grounded but rather comprised a most excellent insulator, the "drag" chains, obviously, could not be expected to discharge the car. Surface resistivities of roadways, as measured by a 1,000 volt d-c megger, between two parallel metal strip electrodes, each 4 inches long, and separated about 1/4 inch, ranged between 1,500 megohms and values well beyond the 2,000-megohm meter scale. Also tests taken of the resistance through the pavement to the ground beneath indicated values of a similarly high order. This was equally true for asphalt and concrete roadways.

In order to control some of the variable factors which influenced the voltage generated by rubber-tired vehicles, many of the tests were conducted on various types of vehicles by means of a high-speed chassis dynamometer. The rear wheels of the car rest upon and drive large drums on this device, which can operate a generator for the purpose of applying any desired value of load to the car. In this way readings of the electrostatic voltage could be taken under any desired load from no-load to heavy loads and at speeds up to 70 miles per hour. Such variables as air currents, changes in humidity, and changing roadway conditions could be eliminated or controlled in these tests. The drums upon which the rear driving wheels operate were grounded, and the voltmeter was connected between any desired part of the car body and the ground. The dynamometer, and one of the many cars tested, together with the various apparatus, are shown in figure 3.

RESULTS OF DYNAMOMETER TESTS

The tests for the voltage which was developed between car body and ground were taken on cars by means of the dynamometer which was operated from speeds of zero to 60 miles per hour at no-load. This condition is equivalent to driving the cars along a level highway without even the resistance of windage. The voltage characteristics for a passenger car and for a five-ton dumper truck are shown in figure 4 as curves, which appear similar in form to the well-known magnetic saturation curve. The three curves for each vehicle are taken for three different pressures of tire inflation. The decreasing rate of voltage rise beyond the knee of the curves for the high speed values implies that a condition of electrification on the tires is approached where further inflow of electrons from the roadway surfaces is increasingly opposed by the intensity of the negative charge already present on the tire treads. This behavior is particularly noticeable for the curves of the lightweight passenger car.

The other voltage-speed curves that are shown in figure 5 for the same car with other values of tire inflation are similar in form, as may be seen, differing only in the magnitudes of the voltages. For the highest tire inflation of the passenger car, the tire loading was 34.5 pounds per square inch, and the voltage is seen to rise to higher values than for lower inflation. From the theory of contact po-

tential difference, this condition is to be expected. With the higher unit loading of the tires, the tire fabrics are forced down into more intimate contact with the microscopically rough and hilly surfaces of the drums in the case of the dynamometer or of the highway in general. For the normal inflation, as shown by the middle curve for the passenger car, the unit tire loading was found to be 31.7 pounds per square inch, and for the lowest inflation, the bottom curve, the loading was 29.1 pounds per square inch. Curves of similar form have been obtained on the highway for voltage versus speed, but the results are more difficult to obtain and are not, in general, as readily reproducible.

The curves for the five-ton truck show that the same general results were obtained as for the passenger car except that at no load the voltage of approximately 13 kilovolts was obtained for a speed of about 40 miles per hour rather than at 60 miles per hour as shown in figure 4 for the lightweight car. This significant fact indicates that much higher voltages would be generated by the truck at higher speeds before the curves reached their maximum values.

The same two vehicles were then given a series of load tests. One such test consists of loading the generator of the dynamometer, while the pounds of push, or tractive effort, at the treads of the rear wheels are increased in order to maintain a constant speed of drive. The effect of this loading on the generated voltage is observed to vary linearly with the tractive effort. These tests were taken at four different speeds for the passenger car and at three different speeds for the five-ton truck as indicated by the curves of figure 5. As the push increases at the treads of the rear tires, the rubber fabrics in tending to slip are forced closer into the interstices of the molecular surface structure of the drums, or roadway, with a resultant increase in the extent of the contacting surfaces and therefore in the proportionate voltage.

In the case of the truck, the slope of the curves of volts versus tractive effort is about 800 volts per 100 pounds of tractive effort, while for the passenger car, the slope is only 300 volts per 100 pounds of tractive effort. The measured values of tire loads for the truck and for the pleasure vehicle are, respectively, 119 pounds per square inch and 34.5 pounds per square inch. If the ratio of these two values of slope voltages is compared with the ratio of the two values of tire loads for the two vehicles, the two ratios are seen to have remarkably close agreement.

This porportionality of voltage to tire loading is in accord likewise with the principle of "contact difference of potential". As explained before, the greater the tire loading, the greater the extent of the surfaces that are pressed into contact, and therefore the greater the voltage. For these and other reasons, it is believed that voltage values ranging between 30,000 and 40,000 volts may be generated on the highways by busses and trucks at high-speed operation.

Additional interesting information was obtained from a number of tests made on a high-speed chassis dynamometer employing drums composed of compressed paper. Since these drums were excellent insulators, rather than conductors, as were the grounded metal drums of the Otis

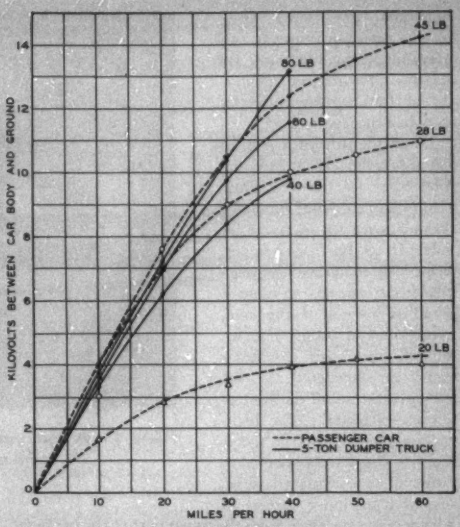


Figure 4. A family of voltage "saturation" curves for the Ford car shown in figure 3 and for a five-ton dumper truck

proving stand, the electric charges that were generated on the paper drums during operation remained on their surfaces. Because of this they neutralized in part the negative charges on the tire treads. The voltages in this case would not be expected to rise to as high values as formerly, and were found not to do so. Steel wire brooms, in which the bristles had been grounded, were then placed upon the surfaces of the drums, so as to permit the positive charges to be neutralized, as rapidly as they were generated, by electrons from the ground. As soon as this was done, the voltage increased to about double its former value.

These tests also clearly demonstrated the effect of increasing temperature on lowering the generated voltage. Since the paper drums are likewise excellent heat insulators, the temperature of the tires increased appreciably with the duration of the voltage-speed tests. The voltage for a no-load test, at first, increased for speeds up to 30 miles per hour, after which it then decreased as the speed was increased up to 60 miles per hour, falling off about 20 per cent from its maximum value. The temperature was approximately 80 degrees Fahrenheit, or about summer heat, whereas the ambient temperature was 63 degrees Fahrenheit. In a subsequent test, when a temperature of about 124 degrees Fahrenheit was attained on the side walls of the tires, the voltage continuously decreased, under no-load and constant speed, from 6,600 volts, by one minute intervals, to 5,600 and then to 3,200. Apparently, from special studies directed to this phase of the electrostatic-voltage generation, the contact difference of potential is lowered as the temperature of the tires is increased. Tires do become warm during operation in the summer months, but in the winter season, in

the cool or cold climates, they run cool. They are cooled in part by natural windage but largely by the cold new areas of roadway with which they are continually coming in contact.

EXPERIENCES ON ROAD TESTS

On many occasions the voltage of the car body was found to decrease as the car slowed down on the highway and to become zero when it stopped. This condition was observed to be coincidental with that of the car body being of negative polarity throughout rather than positive nearest to the tire treads and then negative elsewhere on the body, as was shown in figure 1. These related facts led to the inference that the roadway surface was slightly conductive as the result of a moisture film caused, perhaps, by a certain meteorological condition. Not only did this permit the negative charges on the tire treads to be neutralized as the car stopped, but the tire walls became sufficiently conductive when the car was running to charge the car body by conduction rather than by induc-

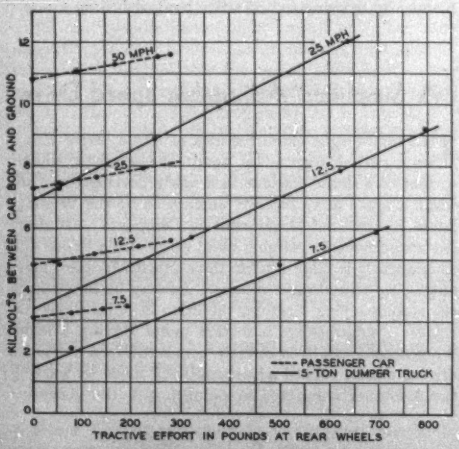


Figure 5. Voltage-load curves for the Ford car and five-ton truck, simulating the condition of ascending steeper and steeper grades at constant speed

tion, and of course, when it stopped, the car readily discharged by the same process. This demonstrates, as has been proved otherwise, that the degree of dryness of the roadway is the all-important factor in determining how long the electrification will remain on the car body.

Discharge tests taken on edges and points of metal of the sharpness of those found on the parts of the car body show that, at the higher voltages, brush discharge causes some lowering of the voltage. This discharge occurs across the side walls of the tires between the positive and negative areas of electrification, as well as from the other parts of the body into the air. This means that a continuous generation of charges must occur, if the voltage is to be maintained at high values.

HAZARDS FROM SHOCKS

Measurements have been taken of the capacitance of pleasure cars with respect to ground, wherein the metal of the car body is considered as one plate of the capacitor and the earth the other, with the dielectric or insulation between as a complex composite of the intervening air, and the rubber tires. These values range from 500 to 650 micro microfarads. For large trucks, busses, and large tank trucks, the capacitance ranges between 950 and 1,500 micro microfarads, and for the body capacitance of people its average value is about 120.

Assume a truck, having a capacitance of 1,000 micro microfarads and charged to a voltage of 20,000 volts, to be touched by a person whose resistance from fingers through his shoes to ground is 20,000 ohms. The current through his body then is limited at the instant of contact by his resistance to a value of 1 ampere, which value reduces to 1/3 ampere in about 20 microseconds, and it becomes about zero in 60 microseconds, after which the truck, as a capacitor, then becomes practically discharged. However, a current of 1 ampere might be dangerous even though of very short duration, and might prove fatal if it should pass through the heart. Very little is known of the physiological effects of current of short duration through the body. Under certain conceivable conditions this resistance might be as low as 2,000 ohms, and the current at the moment of contact could be as large as 10 amperes.

Fortunately, people are normally well insulated from ground by their shoes, which, when dry and soled with rubber, may have insulation resistance as high as 100 megohms. In this case a person who touches an electrified vehicle becomes charged from it just as any capacitor might be charged by conduction from another. Assuming the same numerical values as given for the truck, and that the person touching it has a capacitance value of about 100 micro microfarads and a contact resistance of 3,000 ohms, the first inrush of current would be over 6 amperes, but it would decrease to practically nil in about 1 microsecond. Perhaps in this case only an unpleasant shock would be obtained with the customary tingling effect. Frequently such experiences are passed off in good nature, although strong and robust mechanics are known to have been thrown violently to the ground as a result of severe shocks received from the static electrification of trucks.

PROBLEMS OF CONTROL OF STATIC ELECTRIFICATION ON VEHICLES

Consider again the case in which the body of the vehicle has been discharged of its "free" negative electricity by grounding it, as was previously explained. The tires still retain their high charge of negative electricity and the high positive electrification is still held "bound" at the wheels and fenders. This condition of "discharge" may have been attained through the grounding of the vehicle, say a tank truck, by means of the grounding grids that are sometimes used at the distributing or bulk stations of gasoline companies. Yet the potential hazards of sparks still remain. Any conducting object that is allowed to touch the tire and the fender may produce the necessary spark to ini-

tiate a fire or explosion. Quite likely many of the "mysterious" fires in and about these bulk stations have been started in just this way. Nor does one such discharge terminate the difference of potential at these locations. Since the rubber of the tire is an insulator, only those negative charges on the tire where the conducting object touches are neutralized by an equal number of positive charges on the fender. The resulting spark may be feeble in many instances, but in others a strong, vigorous spark may result. Demonstrations simulating these conditions have established the validity of these conclusions, and they have proved how ineffectual the elaborate grounding grids at the distributing stations of the oil companies may be as safeguards against the fire hazards of static electricity.

With the body of the vehicle discharged of the "free" electrification by grounding it, as previously explained, a sense of false security from the latent dangers of static electricity all too often results. To see how hazards of sparks still may exist despite the elaborate practices of grounding, assume that the grounding connection has been removed. If now the negative electricity on the tires becomes neutralized or discharged in any manner, the previously "bound" positive electrification at the wheels and fenders is released, and it then distributes itself over the surface of the body identically as did the "free" negative charges just prior to the grounding procedure. Now the full force of the fire and explosion hazards of the static electricity is again present, although the truck body was duly grounded and the normal negative electrification of the body discharged. Such are the "lurking" dangers that hover about as menaces to safety, and unless these hazards are recognized and preventive procedures established to dissipate their latent energies, continued loss of life and property is the inevitable consequence.

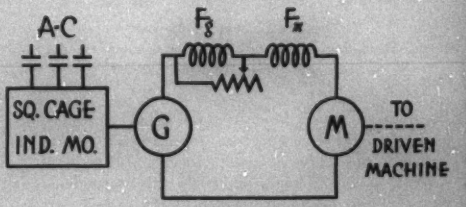
Progress in solving these problems of static electricity on rubber-tired vehicles has been retarded throughout the years by lack of recognition of the basic elements of the problem. Many "crackpot" and costly attempts to solve the problem without any knowledge of the offending elements have led to the uses in varying degrees of "drag" chains, or of rubber ribbons surfaced with conducting coatings attached to the under chassis of busses and trucks, or of tires painted with conductive coatings of graphite or aluminum, or even of tires marked with pencil lines. In fact, tires have been placed on the market that are made of so-called conductive rubber—that is, of rubber whose normally high resistivity has been considerably lowered by the addition of "loading" ingredients possessing conductive qualities.

None of these attempted methods of solution recognizes the element of generation of the electrification, where it occurs, or particularly how the charges are stored on the body of the vehicle. If the tires were highly conductive, say even of metallic composition, as long as the roadway continues to be an excellent insulator the generation of high electrification is fundamentally unchanged. Obviously, too, if the roadway possessed high resistivity, the charges on the tires could not readily flow away, and therefore they would remain on the body of the vehicle, possibly for hours. The charges in the case of conductive tires would not be induced on the body of the vehicle as shown in figure 1. Instead, the negative charges would flow, by conduction, to the wheels and thence to the other metal parts of the body, and the difference of potential between the body and the ground would be determined by the amount of charge generated at the tire treads, much as it is in the case of the normal type of rubber tires.

The author hopes that his efforts to present the fundamental elements of static electricity on rubber-tired vehicles in these studies will be rewarded by their giving encouragement to others to attack various phases of the problem. Perhaps methods of reducing the generation of charge at the tire treads may be devised. This would strike at the very heart of the problem. A study of simple means for discharging the static electricity as it is generated offers an attractive field for investigation. Basically the civil engineer has an interest, if not a definite responsibility, in the problem, since the laying of modern highways which possess these high resistivities is a product of his conception. Perhaps he can solve the problem in some manner by devising a conductive road surfacing.

A Simplified Adjustable-Speed Drive

THE high-torque characteristics of a d-c series motor are combined with a flat speed characteristic similar to that of a shunt machine in a newly developed a-c adjustable-speed drive recently announced by the Westinghouse Electric and Manufacturing Company. The drive has a continuously variable speed range of ten to one and consequently is more flexible than adjustable-speed units employing wound-rotor motors. As may be noted from the accompanying diagram, the drive includes three machines: a squirrel-cage induction motor driving a series d-c generator which is directly connected to a d-c series driving motor. Speed adjustments are made by varying the resistance connected in parallel with the generator



series field. This type of drive is applicable to a wide variety of industrial power applications requiring from 1 to 15 horsepower. As line-start induction motors are used, the set is started and stopped by means of push-button control. As the output of the self-excited generator builds up gradually under normal starting conditions, the driving motor is "cushioned" against mechanical shock.

Daytime Photoelectric Measurement of Cloud Heights

MAURICE K. LAUFER LAURENCE W. FOSKETT

Information on the height of the cloud ceiling, vitally important to airplane pilots, now may be obtained during the day as well as at night. The use of the "ceiling projector" has been extended to daytime measurements by means of a photoelectric detector developed by the National Bureau of Standards for the United States Weather Bureau.

THE height of the cloud ceiling and information concerning the rate at which it is rising or falling above an airport are of particular interest to the pilot who is scheduled to land at that airport within an hour or so. In the United States and Canada, the meteorological services use "ceiling projectors" at airports to determine the height of ceilings at night. The intense beam of light from such a projector forms a conspicuous spot on the base of the cloud. A simple optical instrument at some known distance from the projector is used to measure the angle between the line of sight on the spot and the line of sight on the projector. The tangent of the angle of elevation of the spot, multiplied by the base-line distance from the optical instrument to the projector, gives the height of the ceiling when the base line is horizontal and the projected beam is vertical.

Several years ago, W. E. Knowles Middleton of the Canadian Meteorological Service initiated the first work on a photoelectric detector that would extend the use of the ceiling projector to the daytime measurement of cloud heights through the utilization of a modulated beam. Modulating a projected beam so that, after scattering, the light retains its original "identification tag" was suggested in 1935 by Tuve[1] as a possible means of studying the upper atmosphere. The United States Weather Bureau requested the National Bureau of Standards to develop the necessary equipment for measuring ceiling heights in this way during the daytime.

MEASURING EQUIPMENT

Figure 1 shows schematically the arrangement of the equipment developed. The projector consists of a 24-inch parabolic mirror equipped with an a-c-operated high-intensity *A-H6* mercury-vapor lamp. The modulation of the beam is approximately 95 per cent[2] and has a frequency of 120 cycles per second when the lamp is operated on 60-cycle current. A photoelectric tube and 8-inch lens are used to detect the modulated light signal after reflection from the cloud ceiling. The signal is amplified by a five-stage 120-cycle resistance-capacitance tuned amplifier. In practice the detector scans the base of the cloud until the output meter indicates that the light signal is being received. The angular setting of the detector then corresponds to the angular elevation of the spot on the cloud.

EFFECT OF BACKGROUND BRIGHTNESS

The method described would seem to make it possible to sort out completely the modulated light signal from the background light of the cloud, but the "shot noise" of the photoelectric tube resulting from the background light limits the detection. The shot noise is caused by the fact that photoelectrons are emitted at random, even when the illumination is constant. The analogous "shot effect" in thermionic emission is well known. Thus the photoelectric-tube current produced by a constant background light may be considered as consisting of a steady component equal to the average current with a random varying current superimposed. This varying current produces across the photoelectric-tube load resistor a varying potential that is amplified in the same way as the modulated signal and may obliterate the signal.

Statistical theory shows that the rms value of the varying current is proportional to the square root of the average current and the resulting amplified noise is proportional to the square root of the effective band width of the amplifier. In order to keep the average photoelectric-tube current produced by the background at a minimum, the optical system of the detector was designed to pick up an area on the ceiling no larger than the spot illuminated by the projector. A diaphragm was located at the focus of

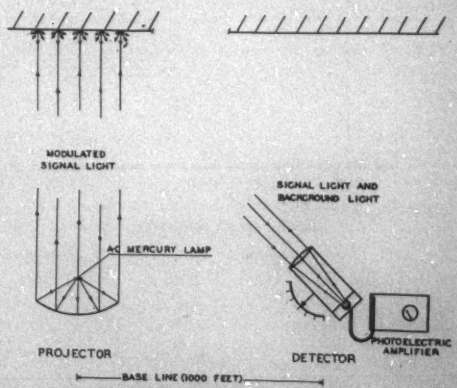


Figure 1. Schematic diagram of equipment used to measure the height of cloud ceilings

Based on a paper presented at the ninth annual meeting of the Institute of Aeronautical Sciences, January 29–31, 1941, New York, N. Y.

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the 8-inch glass lens, and an RCA 929 photoelectric tube was placed immediately behind the diaphragm. The 929 photoelectric tube was chosen because its response is high in the spectral region where the mercury lamp emits most of the energy usable in a glass system. With this setup, photoelectric-tube currents as large as 25 microamperes have been obtained when the detector is directed at clouds illuminated by direct sunlight. Such a current is more than 10^6 times the signal current obtained for moderately high ceilings.

Johnson[3,4] has shown that, if the band width of the amplifier is sufficiently narrow, the limit of detection of an

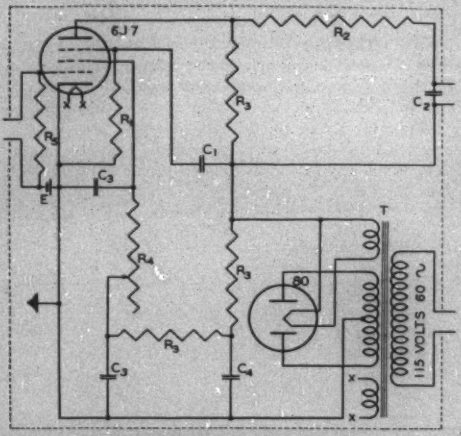

Figure 2. Wiring diagram of output circuit having the following circuit constants:

	Microfarads		Megohms
C_1	0.0001	R_1	20
C_2	4.	R_2	3
C_3	40	R_3	0.1
C_4	4	R_4	0.1
		R_5	0.5

T 830 volts, center-tapped
E 1.25 volts grid bias cell

a-c signal in the presence of a random background noise depends only on the period of the output meter. The amplifier used has an effective band width of 100 cycles, which is narrow enough to make the minimum detectable signal dependent only on the period of the output meter if the background noise results from statistical causes; that is, if the background brightness of the clouds is constant. But during the time the scanning is made to find the spot, the background brightness will be varying, and, moreover, there may be large changes in brightness from cloud to cloud. The resulting variations in background noises may cause a change in the output current many times that produced by the signal when the spot is located, making it quite impossible at times to locate the spot.

If, however, a 120-cycle synchronous commutator, which is phased with the signal, is introduced between the amplifier and the meter, the average output current in the absence of the signal will be zero, because of the random phase of the amplified noise. Thus the variations in brightness of the clouds will not give a false indication of the signal, since the same average zero reading will be obtained for the noise whether the average photoelectric-tube current is 25 microamperes or 2 microamperes. A second advantage results because effectively an increased scale length can be used for the output meter. Normally the noise would produce an average reading 10 to 100 or even 1,000 times that resulting from the signal, but if the average noise-output current is reduced to zero, the entire scale of the meter can be used for indicating the signal.

OUTPUT CIRCUIT

An "electronic switching-circuit", which performs the same function as a synchronous commutator, is shown in figure 2. The rectified but nonfiltered output of the transformer is the plate supply for the 6J7 tube. If the resistance R_4 is correctly adjusted, the plate current consists of square-topped pulses which are maintained for approximately 1/240 second. The time average of the IR drop across the plate resistor R_3 can be obtained from the potential across the capacitor C_2. This potential is reasonably steady because of the long period of the series circuit consisting of R_3 and C_2. Furthermore, the magnitude of this potential is almost completely independent of the amplified noise from the amplifier because of the random phase, as in the case of a synchronous commutator. When a sustained and phased 120-cycle signal is added, the potential across C_2 increases or decreases, depending on whether the positive or negative portion of the signal is present during the time the plate current is flowing. A vacuum-tube voltmeter is used to indicate the change in the potential across C_2.

RESULTS

During the daytime, dark overcast clouds at an elevation of 9,000 feet have been detected readily with the equipment described. For cumulus clouds illuminated by direct sunlight and having elevations up to 4,000 feet, the detection is positive.

In order to determine the minimum signal which can be detected with certainty in the presence of a background light, battery-operated incandescent lamps were used to produce the background light. A signal light about 5×10^{-7} times the background light was detected; this is less than twice the theoretical minimum.

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New Building Wires Recognized by 1940 Code

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The significance to plant engineers of the small-diameter and other new types of building wires, and the changes in temperature limits and current-carrying capacities, recognized by the 1940 edition of the National Electrical Code

THE 1940 edition of the National Electrical Code recognizes 19 different types of building wire. Only 7 of these are rubber-covered building wires, yet when an electrical engineer thinks of building wire he almost instinctively calls to mind rubber-covered wire. This is because rubber insulation has been so generally satisfactory that it is produced and used in a volume vastly in excess of all the other types of wires combined. Within its temperature and voltage limits it has no peer. Most of this article therefore will be devoted to rubber-covered wires, although other types will be mentioned briefly.

The various types of insulated wire with their type letters, are listed in table I, with a brief description of the insulation, the outer covering, and the recognized use. Type *R* is the old familiar code-grade rubber which has been recognized in the Code for over 30 years. In fact, recently some of this wire was removed during remodeling of the Chicago testing station of Underwriters' Laboratories, Inc., after it had been in use for 35 years, and under test was found still to have good dielectric and physical properties. Its temperature limit is 50 degrees centigrade, however, and that limitation forms the basis for much of the change that has taken place and for a tremendous amount of development work on the part of the wire industry.

Type *RW* wire is very similar to type *R* except that it is compounded so as to have more resistance to moisture, a most desirable feature where continuously exposed to moisture as in underground runs. This wire has been recognized in the Code for only a few years and therefore does not have the background of experience of type *R*, although some manufacturers have been making a similar product as a specialty with much success over a period of years.

Type *RP* is a performance-grade rubber, specially compounded to have a higher resistance to heat than code rubber, and is recognized up to an operating temperature of 60 degrees centigrade, which, as table II shows, has a decided bearing on its current-carrying capacity.

Wire of *RH*, or heat-resistant, type has even greater resistance to heat and is recognized for continuous operation at 75 degrees centigrade. This type represents the highest development to date in rubber-covered building wire.

Type *RHT* is merely a small-diameter type *RH*, the *T* standing for a thinner insulation. This material has exactly the same limitations, temperature and otherwise, as type *RH*.

Type *RPT* is a thin-wall type *RP* insulated wire and is separated in table II from type *RP* because it is used only for rewiring in existing raceways, whereas all the materials previously mentioned are for general use. Type *RU* is a rubber-insulated wire of very small diameter on account of the thinness of the rubber insulation. It is made by a special process and contains 90 per cent pure rubber. It has an excellent record to date in the limited applications where it has been permitted. The temperature limit on this unmilled grainless rubber is 60 degrees centigrade. It is limited likewise to the rewiring of existing raceways.

Type *SN* is a wire with a so-called synthetic insulation, meaning presumably that it is man-made from totally different materials. *SN* wire is limited to 60 degrees centigrade and to use in existing raceways, but is made in larger sizes than are the other materials for rewiring. This material differs from the others in several respects. For one thing, there is no necessity for an outer fibrous covering, because of the toughness of the insulation and the relatively inert character of the synthetic material which does not need protection from the light as rubber insulation does. It is, however, slightly subject to cold flow under pressure and tends to be brittle at temperatures below freezing.

The question is frequently raised as to why these special wires of small diameter are limited to rewiring use. The answer, I believe, lies in the desire of the electrical committee of the National Fire Protection Association to proceed slowly with the recognition of new products and give them an opportunity to prove their worth under limited conditions of use before extending recognition for general use. I believe there was a desire also to provide some leeway for future expansion of facilities in a building having concealed raceways that can be changed only at prohibitive expense. If the loading of the circuits increases later as it has in the past, a little space would remain for pulling in additional wires under limited circumstances, if all the available space had not been utilized originally.

Type *SNA* is a combination of synthetic insulation and asbestos. It is a switchboard wiring material of little interest from a building-wire standpoint.

Type *V* is the old familiar varnished-cambric wire that has been used for many years. Its new operating tem-

Essential substance of an address delivered before the power group of the AIEE New York Section, New York, N. Y., February 18, 1941.

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Table I. Conductor Insulations—600 Volts

(1940 National Electrical Code)

Trade Name	Type Letter	Maximum Operating Temperature	Insulation	Thickness of Insulation	Outer Covering	Use
Code	R	50C (122F)	Code-grade rubber	14–10 ... 30/32 in. 8–2 ... 45/64 in. 1–4/0 ... 60/64 in. 250–500 ... 90/64 in. 501–1,000 ... 120/64 in. Over 1,000 ... 150/64 in.	Moisture-resistant flame-retardant fibrous covering	General use
Moisture-resistant	RW	50C (122F)	Moisture-resistant rubber	Same as Type R	Moisture-resistant flame-retardant fibrous covering	General use or in wet locations. See section 3055
Performance	RP	60C (140F)	Performance-grade rubber	Same as Type R	Moisture-resistant flame-retardant fibrous covering	General use
Heat-resistant	RH	75C (167F)	Heat-resistant grade rubber	Same as Type R	Moisture-resistant flame-retardant fibrous covering	General use
Small diameter building wire (heat-resistant)	RHT	75C (167F)	Heat-resistant grade rubber	14–10 ... 30/32 in. 8 ... 45/64 in.	Moisture-resistant flame-retardant fibrous covering	General use. See 3005-d
Small diameter building wire (performance)	RPT	60C (140F)	Performance-grade rubber	14–10 ... 30/32 in.	Moisture-resistant flame-retardant fibrous covering	Rewiring existing raceways. See 3005-e
Type RU wire (See note)	RU	60C (140F)	90 per cent unmilled grainless rubber	14–10 ... 18 mils	Moisture-resistant flame-retardant fibrous covering	Rewiring existing raceways. See 3005-e
Solid synthetic (See note)	SN	60C (140F)	Solid flame-retardant moisture-resistant synthetic compound	14–10 ... 30/32 in. 8 ... 45/64 in. 6–2 ... 60/64 in. 1–4/0 ... 90/64 in.	None	Rewiring existing raceways. See 3005-e
Asbestos synthetic	SNA	90C (194F)	Synthetic and felted asbestos	14–8 Synthetic ... 20 mils Asbestos ... 20 mils	Cotton braid thickness, 20 mils	Switchboard wiring
Varnished cambric	V	85C (185F)	Varnished cambric	Same as Type R except 8 ... 45/64 in.	Fibrous covering or lead sheath	Dry locations only. Unless lead sheathed. Smaller than No. 6 by special permission
Asbestos varnished cambric	AVA	110C (230F)	Impregnated asbestos and varnished cambric	See table	Asbestos braid	General use dry locations
Asbestos varnished cambric	AVB	90C (194F)	Same as Type AVA	See table	Flame-retardant cotton braid	General use dry locations
Asbestos varnished cambric	AVL	110C (230F)	Same as Type AVA	See table	Lead sheath	General use wet locations
Asbestos	A	200C (392F)	Felted asbestos	14–8 ... 40 mils 6–2 ... 60 mils 1–4/0 ... 90 mils 250–1,000 ... 120 mils	With or without asbestos braid	Dry locations only. Not for general conduit installation. In raceways, only as leads to or within apparatus. If without braid or moisture-resistant treatment, limited to 300 volts
Impregnated asbestos	AI	125C (257F)	Impregnated felted asbestos	Same as Type A	With or without impregnated asbestos braid	
Paper		85C (185F)	Paper		Lead sheath	As permitted by 2304-b, or by special permission
Slow burning	SB	90C (194F)	3 braids impregnated fire-retardant thread	Same as Type V	Outer cover finished smooth and hard	For use only in dry locations where the room temperature exceeds 85C (185F)
Slow burning weatherproof	SBW	90C (194F)	2 layers impregnated cotton thread	Same as Type V	Outer fire-retardant coating	For use only in dry locations where the room temperature exceeds 85C (185F)
Weatherproof	WP	80C (176F)	At least three cotton braids impregnated	14–12 ... 30/32 in. 10–2 ... 45/64 in. 1–4/0 ... 60/64 in. 225–500 ... 90/64 in. 525–950 ... 105/64 in. 1,000 and over 120/64 in.		May be used for interior wiring only by special permission

perature of 85 degrees centigrade is a recognition of advancement in the type of varnish used, since the previous maximum was 75 degrees centigrade.

Types *AVA*, *AVB*, and *AVL* are combinations of asbestos and varnished cambric, with an asbestos outer braid and a temperature limit of 110 degrees centigrade for the first, a cotton outer braid and a limitation of 90 degrees centigrade on account of this cotton for the second, and a leaded jacket for use in wet locations for the *AVL*.

Types *A* and *AI* are asbestos-insulated wires having a heat-resistant impregnation in one case and a moisture-resistant impregnation in the other and temperature

limits of 200 and 125 degrees centigrade respectively, in recognition of the difference in these impregnating materials. This is the first effort of the asbestos-wire manufacturers to differentiate among their materials in the National Electrical Code. Heretofore type *A* has covered a multitude of types. It still covers several general types which should and probably will have individual designations.

Types *SB*, *SBW*, and *WP* are specialty wires for limited use. Probably plant engineers are likely to be interested in these wires only where they are run on insulators, a practice still common in mill buildings in some sections of the United States.

A paper-insulated cable also is recognized, but has very limited application under the Code, being primarily an underground-duct type of cable for use by electric utilities.

Three features of the changed wiring tables in the 1940 Code are of particular interest, in my estimation. One is the setting of a definite room temperature of 30 degrees centigrade, 86 degrees Fahrenheit, as a basis of calculation. Another is the difference in current-carrying capacities of the different types of insulation. The third is the recognition of a small-diameter wire and correspondingly the permission to use this small-diameter wire to advantage by having it fill a greater percentage of the conduit area.

In previous editions of the Code, the temperature limit of 49 degrees centigrade for rubber-covered wires and cables was an ambient air temperature without reference to the basic room temperature. This frequently caused confusion. The adoption of an average temperature of 30 degrees centigrade for the basic room temperature therefore represents definite progress and serves as a guide to installation inspection authorities throughout the United States. It is well known that this temperature will be exceeded in many localities for periods of several hours, but in only a few will a 24-hour average be in excess of 30 degrees centigrade. In those localities the higher temperature must be taken into consideration and the current-carrying capacity of the wires reduced accordingly. In special locations also, such as boiler rooms, where the temperature is consistently above 30 degrees centigrade, a correction factor must be applied.

Some inspection authorities, even in the North, are concerned about the temperature in attics, because it is above the assumed basis of 30 degrees centigrade. When it is considered, however, that the high temperatures in attics are for relatively few hours' duration, and only during the summer months, and that the highest temperatures seldom coincide with the heaviest demand for power, it is my belief that little concern need be felt about such locations. A similar situation exists in factories and should be treated in a similar manner. In every consideration of rubber-covered wire, it must be realized that a considerable factor of safety is built into the wires and high temperatures can be withstood for appreciable periods of time without serious injury, even though every such exposure tends to hasten the deterioration of the rubber. Even with considerable depreciation of the rubber, the insulation retains its dielectric strength unless the wire is moved to an extent that causes cracking of the rubber.

Table II. Allowable Current-Carrying Capacities of Conductors in Amperes

For Not More Than Three Conductors in Raceway or Cable Based on Room Temperature of 30 Degrees Centigrade or 86 Degrees Fahrenheit
(1940 National Electrical Code)

Size AWG or MCM	Rubber Type R	Rubber Type RW	Synthetic Type SN Type RU Rubber Type RPT	Rubber Type RHT	Paper Synthetic Type SNA Asbestos Var-Cam Type AVB	Var-Cam Type V	Asbestos Var-Cam Type AVA	Impregnated Asbestos Type AI	Asbestos Type A
	Type RP	Type RH							
14	15	18	22	23	28	29	32		
12	20	23	27	29	36	38	43		
10	25	31	37	38	47	49	54		
8	35	41	49	50	60	63	71		
6	45	54	65	68	80	85	95		
5	52	63	75	78	94	99	110		
4	60	72	86	88	107	114	123		
3	69	83	99	104	121	131	145		
2	80	96	115	118	137	147	163		
1	91	110	131	138	161	172	188		
0	105	127	151	157	190	202	223		
00	120	145	173	184	217	230	249		
000	138	166	199	209	243	265	284		
0000	160	193	230	237	275	308	340		
250	177	213	255	272	315	334	372		
300	198	238	285	299	347	380	415		
350	216	260	311	325	392	419	462		
400	233	281	336	361	418	450	488		
500	265	319	382	404	468	498	554		
600	293	353	422	453	525	543	612		
700	320	385	461	485	562	598	668		
750	330	398	475	502	582	621	690		
800	340	419	490	514	600	641	720		
900	360	434	519	556					
1,000	377	455	543	583	681	730	811		
1,250	409	493	589	643					
1,500	434	522	625	698	784				
1,750	451	544	650	733					
2,000	463	558	666	774	839				

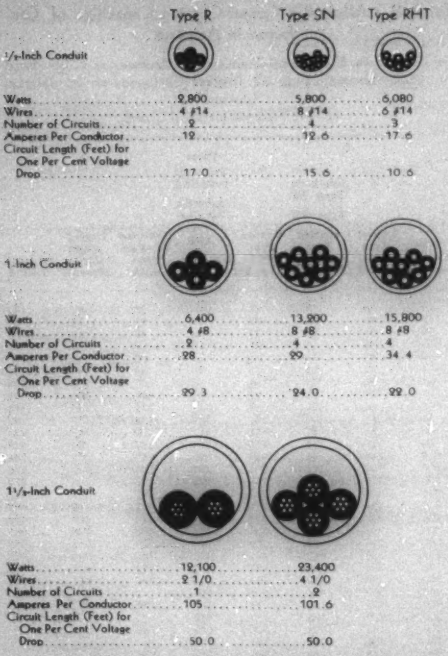
Correction factor for room temperatures over 30 degrees centigrade

C.	F.							
40	104	0.71	0.82	0.88	0.90	0.94	0.95	
45	113	0.50	0.71	0.82				
50	122	0.00	0.58	0.75	0.80	0.87	0.89	
55	131		0.41	0.67				
60	140		0.00	0.58	0.67	0.79	0.83	0.97
70	158			0.35	0.52	0.71	0.76	0.93
75	167			0.00				
80	176				0.30	0.61	0.69	0.89
90	194					0.50	0.61	0.86
100	212						0.51	0.82
120	248							0.72
140	284							0.63

NOTE: If the raceway contains from four to six conductors, the values in the table are reduced to 80 per cent. If the raceway contains from seven to nine conductors, the values in the table are reduced to 70 per cent.

The changes in current-carrying capacities of conductors as indicated in table II (table I of the Code) have caused some misunderstanding and no little criticism. Nevertheless these changes were necessary if the Code is to be kept in line with the engineering information available, as of course it must be.

In January 1938, S. J. Rosch, of the Anaconda Wire and Cable Company, in a paper delivered before the AIEE winter convention [*AIEE Trans.*, *'38 (March)*, *p. 155–67*] gave the basis for the current-carrying-capacity tables that now have been incorporated in the Code in modified form. The comparison in table III of the 1937 Code and the 1940 Code shows how extensive these changes in current-carrying capacity have been. In the larger sizes the changes would be alarming if it were not that practice over a period of years has tended toward lower


Type R
Type SN
Type RHT
½-Inch Conduit
Watts 2,800 5,800 6,080
Wires 4 #14 8 #14 6 #14
Number of Circuits 2 4 3
Amperes Per Conductor 19 19.6 17.6
Circuit Length (Feet) for One Per Cent Voltage Drop 17.0 15.6 10.6
1-Inch Conduit
Watts 6,400 13,200 15,800
Wires 4 #8 8 #8 8 #8
Number of Circuits 2 4 4
Amperes Per Conductor 28 29 34.4
Circuit Length (Feet) for One Per Cent Voltage Drop 29.3 24.0 22.0
1¼-Inch Conduit
Watts 12,100 23,400
Wires 2 1/0 4 1/0
Number of Circuits 1 2
Amperes Per Conductor 105 101.6
Circuit Length (Feet) for One Per Cent Voltage Drop 50.0 50.0

Typical examples of increased circuit capacity made possible by rewiring with the small-diameter building wire

All computations based on two-wire 115-volt circuits

values than those theoretically permissible according to the Code. This means that engineers doing layout work were aware that if cables were loaded to the full capacity permitted by the Code, overheating and unsatisfactory operation generally would result. The changes, therefore, are more theoretical than actual where a good engineering job was done, but will require more changes in those installations where the job was done by rule of thumb and where voltage drop was not the dominant factor, as in most instances it is and should be.

The problem of voltage drop is not covered in detail in the Code, although mention is made of the fact that the tables are based on temperature alone and do not take voltage drop into consideration. Nevertheless, if the minimum sizes of wire given in the Code are used, the voltage drop is so great that I believe this factor actually more important than the temperature of the wires under full load in determining the size of wire that should be used.

In section 2202 of the Code the statement is made that the size of feeders should be such that the voltage drop up to the final distribution point for the load will be not more than one per cent for lighting loads or combined lighting and power loads and three per cent for power loads. In view of that statement, tables V and VI were prepared to show the allowable circuit length for different sizes of wire and conduit where a maximum of one per cent drop is contemplated. The circuit lengths are exceedingly small. While theoretically greater values of current could be utilized by using rubbers permitting higher temperatures, practically, a larger size of wire has to be used on account of voltage drop regardless of the type of rubber. Therefore, for small sizes of wire, the highest temperature insulation and the different current values based on it will have little significance. High-temperature rubber does, however, give a greater range to rubber-covered wire and permits its use in locations where, for reasons of temperature alone, another and in some respects less suitable type of wire has had to be substituted in the past.

In the larger sizes, the change in permissible current is much more significant because voltage drop is not so important a factor. Comparison of the current-carrying capacities in the 1937 and the 1940 Codes as given in table III shows that the current-carrying capacity of Code-grade wire has been reduced radically. The 1937 current-carrying capacities for type *R* compare favorably with the 1940 current-carrying capacities for heat-resistant grade of insulation (*RH*). This probably will result in the use of the higher grades of insulation for the larger cables. As pointed out, rubber-covered wire in the larger sizes has not been used to any great extent to carry the full-load current for which it formerly was rated, so the change will mean that the values now given in the Code actually can be followed because they are scientifically based.

There has been a great deal of discussion on this phase of the change in the current-carrying capacity tables, particularly from those who have installed cables for others

Table III. Comparison of Current-Carrying Capacities of the 1937 Code and the 1940 Code

Current-Carrying Capacities in Amperes, Conductors in Raceways (1940 National Electrical Code)

Size AWG or MCM	Type R 1937 Code	Type R 1940 Code	Type RH 1940 Code
14	15	15	22
12	20	20	27
10	25	25	37
8	35	35	49
6	50	45	65
4	70	60	86
2	90	80	115
1	100	91	131
0	125	105	151
00	150	120	173
000	175	138	199
0,000	225	160	230
250	250	177	255
300	275	198	285
350	300	216	311
400	325	233	336
500	400	265	382
600	450	293	422
700	500	320	461
750	525	330	475
800	550	340	490
900	600	360	519
1,000	650	377	543
1,250	750	409	589
1,500	850	434	625
1,750	950	451	650
2,000	1,050	463	666

Table IV. Per Cent Area of Conduit or Tubing

(1940 National Electrical Code)

	Number of Conductors				
	1	2	3	4	Over 4
Conductors (not lead covered)	53	31	43	40	40
Lead-covered conductors	55	30	40	38	35
For rewiring existing raceways with conductors of thinner insulation, as provided in 3005-d and e	60	40	50	50	50

rather than for their own use. For plant engineers making installations for their own use, the change is highly desirable and results in bringing the provisions of the National Electrical Code into conformity with the latest engineering information.

The other significant change in the recognition of wires is the small-diameter building wire. This was sponsored by the electrical utility companies, which frequently were confronted with the difficult situation of a building wired with concealed conduit, the conduit filled to capacity on the basis of the old Code, and a greater number of circuits desired by the tenant or building owner. To pull out the old conduit and install new would be exceedingly expensive. They therefore have desired to use smaller-diameter wires having a higher grade of insulation that would give suitable performance despite the thinner insulation.

The Code therefore recognized small diameter wires in higher grades of insulation, such as the performance grade *RP*, the heat-resistant grade *RH*, the 90 per cent unmilled grainless rubber *RU*, and the synthetic insulation *SN*.

Table V. Circuit Length of Type R Wire in Feet to Give One Per Cent Drop

115-Volt Star, Source of Voltage Supply; Single-Cable Conductors, One-Phase Basis; Unity Power Factor

AWG or MCM	Allowable Current*	Circuit Length (Feet)	Number of Wires in Conduit	Size of Conduit (Inches)
14	15	17.3	4	1/2
		20.2	7	3/4
		20.2	9	1
12	20	16.4	3	1/2
		20.7	5	3/4
		23.6	8	1
10	25	25.9	4	3/4
		25.9	6	1
8	35	23.6	2	3/4
		29.3	4	1
6	45	28.2	2	1
5	52	29.9	2	1 1/4
4	60	32.2	2	1 1/4
3	69	36.2	2	1 1/4
2	80	39.2	2	1 1/4
1	91	43.2	2	1 1/2
0	105	44.9	2	1 1/2
00	120	51.2	2	2
000	138	55.8	2	2
0,000	160	60.0	2	2
250	177	63.9	2	2 1/2
300	198	67.4	2	2 1/2
350	216	72	2	2 1/2
400	233	76.5	2	3
500	265	80.5	2	3

*Maximum three conductors in raceway.

For three per cent voltage drop, multiply circuit length by three.

In conjunction with this recognition, the percentage area of conduit-fill also was increased, permitting a greater number of wires for a given size of conduit and to some extent making possible the increased number of circuits desired. Here again the voltage drop plays a decisive part. Tables V and VI indicate that if the circuits were loaded to capacity, the length of cable that could be used without exceeding the one per cent drop recommended by the Code for lighting circuits would be so small as to be impracticable.

Probably the real situation is that a large number of circuits loaded only partially to capacity are desired, and therefore the smaller diameter wires are an asset primarily

Table VI. Circuit Length of Type RH Wire in Feet to Give One Per Cent Drop

115-Volt Star, Source of Voltage Supply; Single-Cable Conductors, One-Phase Basis; Unity Power Factor

AWG or MCM	Allowable Current*	Circuit Length (Feet)	Number of Wires in Conduit	Size of Conduit (Inches)
14	22	12.1	4	1/2
		13.2	7	3/4
		13.2	9	1
12	27	11.5	3	1/2
		15	5	3/4
		17.3	8	1
10	37	17.3	4	3/4
		17.3	6	1
8	49	15.5	2	3/4
		20.5	4	1
6	65	19	2	1
5	75	20.2	2	1 1/4
4	86	21.8	2	1 1/4
3	99	23.6	2	1 1/4
2	115	26.4	2	1 1/4
1	131	28.2	2	1 1/2
0	151	30.5	2	1 1/2
00	173	32.8	2	2
000	199	36.2	2	2
0,000	230	39.1	2	2
250	255	40.8	2	2 1/2
300	285	43.1	2	2 1/2
350	311	45.5	2	2 1/2
400	336	48.9	2	3
500	382	51.8	2	3

*Maximum three conductors in raceway.

For three per cent voltage drop, multiply circuit length by three.

because of their physical dimensions, and not on account of their higher current-carrying capacity. The higher current-carrying capacity is, in this particular case, a by-product of the higher grade of insulation necessary to permit the use of a smaller amount of insulation.

Only in those places where a very short run of cable will be suitable can the full current values permitted for the higher grades of insulation be utilized without having excessive voltage drop.

The significance of the foregoing to plant engineers, is that rubber-covered wires now have a wider range with respect to temperature than those previously recognized in the Code. For some specific applications a larger number of wires can be run into old conduits and a much greater number of circuits obtained, although, on account of definite limitations in voltage drop, the full value of current theoretically permitted by the tables cannot be utilized.

Another way of looking at this is that with a number of small branch circuits loaded to capacity, where the voltage drop is now a serious factor, more copper can be placed in the same conduit under the rewiring rules and the same load carried with a much lower voltage drop. This is a significant feature which promises more than the idea that a much greater wattage can be obtained in a given installation. To illustrate this, the diagrams on page 214 show the theoretical wattage that some representative conduits can carry, and the circuit length of wire (half the total length for two-wire circuits) that could be utilized under those conditions. As this length is exceedingly short, the practical advantage certainly seems to be that of carrying the same size of load as at present, but with less drop, by the introduction of a small diameter wire.

In the larger sizes of cable, where the temperature has been the limiting factor, the situation is considerably improved. Cables are now available that can be utilized for carrying the full rated load as indicated in the tables and correction factors for numbers of wires, without requiring a layout engineer to make additional reductions based on unfavorable experience with the deterioration of the insulation.

It is hoped that these new wires will help all of us enjoy to the fullest the advantages that the increased use of electricity permits.

Voltage-Operated Earth-Leakage Protection

THE PAPER "Voltage-Operated Earth-Leakage Protection" by T. C. Gilbert, deals with the problem of protection of low-voltage distribution systems from the standpoint of practical experience rather than from a purely theoretical basis, particularly for secondary systems on customers' premises. The author discusses the protection of secondary systems quite thoroughly and sets up the relative importance of the various factors in the problem, such as fire risk, shock hazard, cost of the installation, etc., but with greatest emphasis on the fire risk, since in rural areas this presents the greatest menace.

The limitations of multiple neutral grounding are presented, together with what the author believes to be the only really practical alternate, that of using voltages of the neutral to ground as an indication of an abnormal operating condition, and applying this voltage to a trip coil to disconnect the service by automatically tripping the customer's circuit breaker. Diagrams and pictures of the devices are included. The author refers to English, German, and Swiss practices and quotes excerpts from publications of various governments and others to support his views.

The widespread development of rural electrification has focussed considerable attention on the matter of adequate protection of customers' services. The hazards accompanying rural installations are particularly pronounced because of difficulty in maintaining proper standards of installation, the lack of central water supply systems, the difficulty in effectively fighting fires, and the large number of buildings with inflammable contents on the premises of rural customers.

One fundamental difference which must be considered in comparing British and European practice with that in the United States is the lower service voltages commonly in use here. The foreign practice is to employ 220/380 volts three-phase system, giving single-phase voltages to ground of 220 volts, or double that which would usually be experienced in installations in the United States.

For many years experience in England and elsewhere has tended to establish the use of conduit continuously bonded and grounded throughout as the safest form of construction. In the light of experiences cited by the author, considerable doubt is expressed as to the adequacy of installations of this type, even though it would appear to be about the ultimate in freedom from hazards of all types. Multigrounding the primary as well as the customer's secondary (called "protective multiple earthing", by the author) has been considered as giving the maximum protection against dangerous voltage rise when the secondary conductors are enclosed entirely in metallic conduit.

The use of multiple grounds was primarily developed for the protection against personal shock hazard, and while this may have been accomplished to a considerable extent by overcoming the difficulties of obtaining low resistance to ground at isolated locations, the problem of fire hazard appears to have been considerably aggravated. The problem of fire hazard is further complicated by increasing loads on customers' services, resulting in the use of large fuses, thereby nullifying protection against ground faults. Even if careful tests and inspections are made on the original installation, experience has shown that the resistances of metallic structures such as conduits and water pipes do not stay constant but rise over a period of years. This has been found to be the case even in the use of many gauge threaded joint conduits.

The particular function of multigrounding then is to provide an over-all low resistance to ground through all available ground connections in parallel. Line-to-ground faults may then result in sufficient current to operate protection and to restrict the voltage rise of neutral conductors above ground to safe limits. Theoretically, this type of construction should produce the desired results, but because of breaks in the neutral conductors or higher resistances in the neutral circuit, the earth-return path may

Abstract of a paper of the same title, prepared for the Institution of Electrical Engineers of Great Britain by T. C. Gilbert and abstracted by Frederick Von Voigtlander (A'29, M'38) electrical engineering department, Commonwealth and Southern Corporation, Jackson, Mich.

become one of considerable resistance, particularly in rural areas where detection and maintenance are difficult. Even if the earth-return circuits were of low resistance, experience has shown that nonelectrical metallic circuits may carry considerable current, as cited in the report of the American Water Works Association, and as a result there is the possibility of hot spots developing and the possibility of sufficient current flowing in accidental contacts between gas pipe and conduit, or other metallic structures carrying electricity, to result in damage to such structures either by electrolysis or by fusion at the point of contact.

It therefore follows that multigrounded secondary installations do not accomplish the purpose for which they were developed. The author proposes, as a possible solution to the problem, the use of a device operated on the difference of potential between the neutral conductor and an auxiliary ground to trip the customer's service breaker whenever such a potential exceeds a predetermined minimum. The neutral potential is measured to an auxiliary ground which can have quite high resistance, as only from 60 to 80 milliamperes are required to operate the neutral voltage relay. If 65 volts between neutral and ground were considered the maximum allowable, the circuit could contain a total impedance of close to 1,000 ohms. With the resistance and reactance of the relay coil itself each equal to, say, 200 ohms, the system would operate satisfactorily for an external grounding resistance of the order of 700 ohms. This would provide adequate protection by the use of ordinary driven grounds of the simplest sort. The author cites experiences, particularly in Germany, where such installations have been carried out on a large scale which over a period of 16 years have been found to be very satisfactory.

A further development of this device includes its application to switches controlling heavy appliance outlets to which customers connnected portable tools, farm machinery, etc. Such switches were equipped with the automatic earth-leakage trip devices each having its own voltage trip circuit connected to ground through individual ground rods at the devices.

Such switches, in combination with overcurrent protection, could also be installed on outlets serving water heaters, electric stoves, washing machines, and similar appliances having large metal areas exposed to physical contact, thereby greatly reducing the hazard of personal injury and shock in their use.

The use of neutral voltage operated devices of this type to automatically de-energized customers' services for ground fault enhances the advantage of nonmetallic conduit and nonmetallic sheathed wires which, in the author's opinion, from the standpoint of cost, shock hazards, fire hazards, and maintenance, are in every way superior to the use of multiple grounded neutrals and rigid metallic conduit installations.

Library Versus Laboratory Research

HEARING the word "research", the layman pictures a serious-faced individual in a laboratory, surrounded by mysterious apparatus. Popular conception has a laboratory the essential background, even though that is not the most important or most fertile field for research in many branches of science today.

Science has another setting for research—the library. When scientific literature was lacking or very meager, research necessarily meant laboratory investigation above all else. Today, scientific literature has attained tremendous proportions, and increases much faster than it is digested and efficiently utilized. For that reason it should prove advantageous for the present-day research worker to spend much more time in the library, and correspondingly less in the laboratory, than is the general custom.

Library research would overcome two serious errors often made by scientists, duplication of work described completely and failure to appreciate inventions described almost verbatim in the literature.

Annual reports of the Secretary of Commerce over a period of years indicate that about 30 per cent, more than 15,000 each year, of the patent applications filed are abandoned. The predominant reason for abandonment is that the subject matter disclosed in the application has already been described in published literature. Without question, the annual bill to industry for abandoned applications amounts to several million dollars. Practically every dollar might have been devoted to pioneer research to extend frontiers of our knowledge at a faster and more profitable rate than is now the case. Time would have been saved for all concerned had the literature been thoroughly investigated in the beginning.

Many a scientist is too busy accumulating data to take time for a complete and analytical evaluation of either his own or published data of others. As a result scientific literature increases at an amazing rate and many important inventions are submerged in it. Some of the most important inventions of this era were discovered years after they had been described almost in their entirety in the scientific literature. The last step only was missing, and it took years for the scientist to supply it from the laboratory.

With proper balance and co-operation between the laboratory and the library scientists, millions of dollars wasted annually in repeating old investigations will be saved. The stream of data continually increasing the volume of scientific literature will be carefully searched, correlated and efficiently utilized. Important inventions will be speedily skimmed from the literature instead of reposing unknown and unused. Our industrial research will then attain a new efficiency peak and frontiers of knowledge will expand more rapidly than ever before, to the advantage of scientists, industry, and civilization.

Abstracted from "Library Versus Laboratory Research", by Arthur Connolly, *Industrial and Engineering Chemistry*," October 25, 1940.

Applications of Electric Power in Aircraft

T. B. HOLLIDAY

As a national defense problem of primary importance, the needs of the aviation industry offer a challenge to the designers and manufacturers of electrical equipment. The author lists the following as some of the important needs already recognized, and warns that others may be expected to develop.

1. Engine-driven generators with greater output or decreased weight.

2. A constant-speed drive that would permit the use of alternators with variable-speed prime movers. To meet proper future power needs, this drive should be designed to transmit 30 horsepower and should weigh not more than 30 pounds.

3. Lighter-weight batteries. Unless these can be designed, the aviation industry will be forced to discontinue the use of batteries.

4. An accessory power plant to deliver 7.5 kw, with weight of from 70 to 80 pounds, small size, and reasonable cost.

5. Electric motors with the smoothness and ease of control which characterize hydraulic equipment.

6. Positioning motors that permit accurate remote control of various devices. Present positioning motors are somewhat heavier than is desirable.

7. Radio equipment designed to minimize the problems of installing other electric equipment.

8. Smaller sizes of cable. The development of flame-proof cable and of cable that can withstand more severe usage also would increase reliability of electrical distribution systems.

9. Electric equipment that duplicates the action and smoothness of the hydraulic jack.

10. An electrically operated substitute for hydraulic and pneumatic wheel brakes.

11. Improved circuit-protection devices.

APPLICATIONS for electric power in modern aircraft are many. In nearly every case these applications represent special problems in which the electrical industry as a whole has taken extraordinarily little interest. As a result, the aviation industry has been forced to obtain electrical equipment from manufacturers of special equipment, who are not necessarily the best designers of electrical apparatus. As a result many other types of accessory power have been used for duties which electric power could quite easily perform.

In its simplest form an airplane consists of a fuselage with supporting wing surfaces, a power plant for propulsion, and landing gear for operation on the ground. Any item of equipment which is in addition to the basic airplane and which is not essential to flight can be classified as an "accessory". The purpose of these accessories is to increase the performance of the airplane, provide greater safety, increase reliability, and make the task of operating the airplane an easier one.

These accessories are operated by various types of power: manual, electric, hydraulic, pneumatic pressure, pneumatic suction, mechanical, a combination of these and in some cases the use of gas under pressure. It is the purpose of these types of accessory power to transfer energy from one part of the airplane to another. In nearly every case the basic source of energy is the aircraft power plant which also drives the propeller.

Table I lists many of the accessories of the modern airplane and the types of accessory power used to operate them.

Essential substance of a paper presented at the AIEE Middle Eastern District meeting, Cincinnati, Ohio, October 9–11, 1940 and also at the conference on air transportation at the AIEE winter convention, Philadelphia, Pa., January 27–31, 1941.

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It will be noted that for the first five types of power the engine is the prime mover. In the case of manual power the pilot is the source, and the last, which is termed "combustion" means the product of ignited powder. Of the accessories listed, lighting, radio, and intercommunication equipment can be operated only electrically. For this reason it is essential that the aircraft include a source of electric power. All the remaining accessories can be operated electrically, and in some cases manually as well.

Some combinations of power will be noted. For example, de-icing equipment is operated by an air pump direct-driven (mechanical) by the main engine to deliver pneumatic pressure to rubber boots on the wing-leading edge or other surface from which ice is to be removed. An electric motor also can be used in combination with the air pump.

Obviously it will be to the advantage of the aviation industry to reduce the number of types of accessory power to a minimum, thus reducing the number of power take-offs that must be provided on the aircraft engine. When selecting the type of accessory power, certain characteristics must be considered. The system must be reliable, because in many cases the completion of the flight mission is dependent upon the accessory. Obviously the equipment must be light in weight, because a reduction in weight of the accessory equipment means that more payload or more fuel can be carried. The saving of one pound has an unbelievably high theoretical value in commercial aviation. The installation should be such that maintenance and replacement of items are relatively easy. The cost should not be exorbitant, although cost is usually subordinated to such requirements as reliability and weight. In military aircraft vulnerability is an im-

portant consideration. For that reason an accessory system should be selected which can be duplicated. Additional characteristics that are desirable but too often sacrificed are available power on the ground, ease of control, and quick response.

A comparison of the three most commonly used types of power, electric, hydraulic, and pneumatic, shows that the hydraulic system has many advantages which amply justify its use in aircraft, but also has certain disadvantages, particularly in military aircraft, which make the development of equivalent electric equipment highly important.

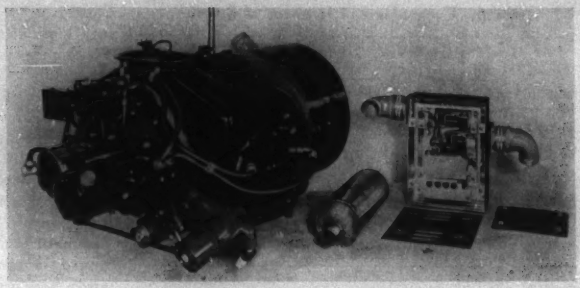

Figure 1. D-c accessory power plant, 5 kw, 28.5 volts, consisting of a two-cylinder internal-combustion engine with a comparatively flat generator mounted on the engine crankshaft

The reliability of the electrical system is rather good, although difficulties encountered in service are many and varied. These are approximately evenly divided between electrical and mechanical failures. Until 1939 the weight of generators and motors could be fairly considered as a disadvantage, but under the leadership of a major manufacturer in the electrical industry these weights have been reduced astonishingly. Electric power has many basic advantages in efficiency, cost, and avoidance of operating difficulties at high altitude and low temperature. It is to be regretted that its other characteristics have not kept pace with those achieved by competitive types of power.

Further discussion will be confined to the electrical system. The conventional practice in the past has been to use generators mounted on and driven by the aircraft engines which are operated in parallel with lead-acid batteries. This d-c system had a normal rating of 12 volts until 1939. At that time practically all new military and commercial airplanes were designed with a 24-volt d-c system. The battery is needed primarily as a reservoir of electric energy for starting the aircraft engines. D-c power is needed because aircraft engines are variable-speed prime movers. To operate the generators in parallel a voltage-regulated d-c system is necessary. Engine speed varies from a maximum at take-off, which is approximately 120 per cent of rated speed, to an operating speed of approximately 60 per cent during cruising at maximum fuel economy. This means that the generators must operate satisfactorily throughout a 2-to-1 speed range.

Table I. Methods of Operating Aircraft Accessories

	Electrical	Hydraulic	Mechanical	Pneumatic Pressure	Pneumatic Vacuum	Manual	Combustion
Engine: Starter	x			x		x	x
Radiator shutters	x					x	
Fuel pumps	x	x	x			x	
Tachometer	x		x				
Controls						x	
Synchronizer	x						
Propeller: Pitch changing	x	x	x				
Constant speed controls	x						
Anti-icing	x						
Wheel retraction	x	x	x			x	
Wheel brakes	x	x		x			
Flap mechanism	x	x	x			x	
Flying controls						x	
Radio	x						
Lighting	x						
Intercommunication	x						
Fuel transfer	x					x	
Heating	x						
Fire extinguisher	x					x	
De-icing	x*		x*	x*			
Gyroscopic instruments	x				x		
Remote instruments	x						
Automatic pilot	x	x*			x*		
Cabin supercharging			x*	x*			
Machine guns	x		x				
Machine-gun rearming	x			x			
Bomb release	x				x		
Bomb doors	x			x	x		
Camera	x				x		

*Combinations of power, see text

GENERATORS

The space allowed for installation of generators on the aircraft engine is limited. In no case can the diameter of the generator exceed six inches, since other accessories and engine auxiliaries must be mounted on and driven by the same rear section. These other accessories and auxiliaries include the engine starter, one or two magnetos, the hydraulic-system oil pump, the pneumatic-system air pump, fuel pump, engine oil pump, tachometer drive, and miscellaneous synchronizing drives. Generators having a maximum weight of 38 pounds have been installed on engines. However, one type of engine caused generators weighing only 32 pounds to shear four 5/16 mounting studs, due to excessive vibration. The number of mounting studs has been increased to six, but it is still preferred to restrict generator weight to approximately 35 pounds. Until approximately two years ago the maximum output needed from a single generator was 50 amperes at 15 volts. This generator was operated with the so-called 12-volt system and was actually set at 14.25 volts properly to charge the batteries. It had an output of 750 watts and weighed 32 pounds.

By doubling the operating voltage and standardizing on a 24-volt system a generator having the same current rating was obtained for a weight of 34 pounds. This

Table II. Current-Time Performance of Batteries

Current	Time in Minutes to Reach End Voltage: 22 Volts	18 Volts
24-Volt 70-Ampere-Hour Battery, Weight 140 Pounds		
50	60	75
100	30	60
200	1.5	11
300	0.8	6
24-Volt 35-Ampere-Hour Battery, Weight 80 Pounds		
50	12	30
100	0.9	10
200	0.4	2
300	0.2	0.8

represented a reduction in specific weight per kilowatt to almost half that previously used. Further development in generators during the current year has resulted in the production of a 100-ampere 30-volt machine (3 kw) weighing only 32 pounds. There is now under development a 200-ampere machine which utilizes additional forced cooling from the slipstream and which will weigh only 37 pounds. This generator represents a specific weight of approximately 6 pounds per kilowatt compared with the 44 pounds per kilowatt previously used. The efficiency of these machines is approximately 75 per cent. They are designed for a minimum speed of 2,500 rpm and must provide accurate voltage regulation to 4,500 rpm. With the expectation that still greater amounts of electric power will be needed within the next five years, engine design is now being revised to provide a higher generator-drive speed.

BATTERIES VERSUS ACCESSORY POWER PLANTS

Batteries are used primarily as a reservoir of electric energy for starting the main engines. The characteristics of batteries which are normally used in aircraft are shown in table II. Consideration of the currents shown in the table clearly indicates that batteries can hardly be considered as a source of assisting power to high-output generators. A battery weighing 140 pounds will deliver 200 amperes at 18 volts or more for only 11 minutes. A generator weighing only one-fourth this amount will deliver 200 amperes continuously and 300 amperes for 5 minutes at 28 volts instead of 18 volts.

Another characteristic of batteries which prejudices against their use is the increase in weight with increase in voltage. A 34-ampere-hour 12-volt battery which has been in use for the past ten years weighs approximately 38 pounds. When the system voltage was doubled it was found that a 24-volt 17-ampere-hour battery, which has the same watt-hour capacity, weighed 56 pounds. This increase in battery weight more than offset other gains which were made with the increase in voltage.

Consequently, it may be necessary to use small engine-driven generators commonly described as accessory power plants instead of batteries, in starting the main aircraft engines. Experimental units of this type have been developed which provide 5 kw continuously and 7.5 kw intermittently in a weight of 140 pounds, which is practically the same as that of a 24-volt 70-ampere-hour battery. The latter will deliver 200 amperes at 18 volts for 11 minutes. The accessory power plant will deliver 175 amperes continuously and 275 amperes for 5 minutes at 28 volts.

Accessory power plants have been developed by the Army Air Corps, the Navy Bureau of Aeronautics, and to a limited extent by commercial aviation interests, with the idea that small engine-generator units could be installed in duplicate in larger airplanes and used as the primary source of electric power, thus making available higher power, higher voltage, and alternating current. The small gasoline engine also could provide power on the ground eliminating batteries. In addition, if electric power were used to distribute energy throughout the airplane, many accessories could be removed from the main engine, simplifying its installation and maintenance.

The Air Corps procured an engine which was rated 30 horsepower at sea level and 12 horsepower at 20,000 feet. The complete installation of two engine alternator units to deliver approximately 13 kw of power weighed 640 pounds. Each engine alone weighed 240 pounds. Subsequent development and procurement have proved that it is entirely possible to provide an equivalent engine with less than 40 per cent of this weight. Difficulties encountered with the first installation were numerous. The flexible coupling installed between the small high-speed engine and the alternator gave trouble because the angular acceleration which resulted from a comparatively small number of cylinders imposed high stresses on these parts. The use of high-frequency alternating current encouraged the development of electric motors operating at a synchronous speed of 24,000 rpm, and this high operating speed caused many failures, all due to failure of lubricants. Most of these troubles have been solved, although the first system cannot be relied upon for continuous use for more than 150 hours without maintenance.

Development of similar d-c accessory power plants has

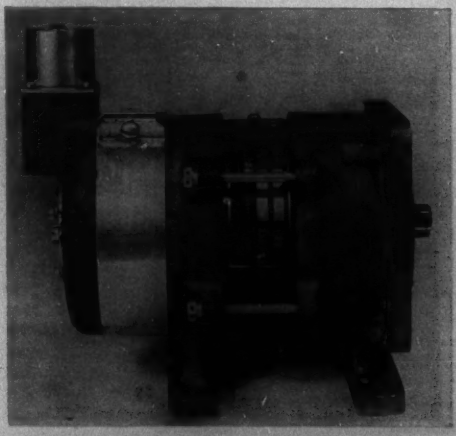

Figure 2. D-c motor, 24 volts, 0.4 horsepower, 2,500 rpm

Figure 3. Motor-driven centrifugal fuel pump

The eight-pole three-phase 400-cycle 110-volt motor has a rating of 1.5 horsepower at 5,700 rpm

resulted in a 5 kw, 28.5-volt unit weighing 140 pounds, which occupies a space 22 inches long, 20 inches wide, and 14 inches high. This power plant is internally supercharged, so that it delivers 80 per cent of its normal rating at 20,000 feet altitude and 150 per cent at sea level. However, operating altitudes now are far above 20,000 feet. In so far as application in military airplanes is concerned, increase in operating altitude in the past three years make it impracticable to consider accessory power plants as the primary source of power. Operating altitudes have increased to 35,000 and 40,000 feet with the use of supercharged cabins for personnel. At such altitudes a supercharger adequate to maintain the necessary electric output from the accessory power plant will be nearly as large as the small engine itself.

The parallel development in engine-driven generators has made it possible to obtain 6 kw from a machine weighing only 37 pounds. A separate engine-driven accessory power plant to deliver the same rating at these altitudes would weigh nearly 200 pounds. The choice is obvious. Vulnerability also affects this selection. In a four-engine airplane, four small d-c generators on the main engines would be a much smaller target than would the equivalent accessory power plants. Four generators would be provided, while it is doubtful if there would be space for more than two accessory power plants, each of which must necessarily have twice the rating of the units driven by the main engines. Loss of one of four generators would be far less important than the loss of one of two accessory power plants.

APPLICATIONS OF ALTERNATING CURRENT

The use of a-c power, developed with the accessory power plants described, proved to have many advantages. For example, a-c power made it possible to provide remote indicating instruments which greatly simplified the transfer of an indication of engine operating conditions to the pilot's instrument board. With previously used instruments, mechanical tachometer shafts, oil-pressure and fuel-pressure lines had to be conducted from the engine compartment to the pilot's board. These lines were vulnerable points in the engine control system.

In addition, the development of fluorescent lighting for instruments was assisted by the availability of a-c power. Improper lighting of instruments causes glare in the pilot's eyes and impairment of vision when it is needed most. The development of instrument lighting progressed from so-called direct lighting to masked indirect lighting and finally to incorporation of a small surgical lamp in each instrument. This last method was the most satisfactory, but was very expensive, since a lamp costing approximately $1 must be installed in each instrument, and wiring conducted thereto. Fluorescent lighting uses ultraviolet radiation to cause radium paint or special paint to fluoresce. This provides ideal lighting, since the numerals on the instrument dial become the source of light and there is no glare.

A-c applications for the operation of radio equipment and gyroscopic instruments are now under development. The latter have been operated in the past by means of pneumatic suction. Use of high-frequency a-c power will make it possible to drive the rotor of these instruments as an induction motor.

These applications for a-c power, which were discovered in experimental development of accessory power plants with a-c systems, are of equal advantage in airplanes whose primary source of electric power is direct current. To provide a-c power in these airplanes various types of inverters have been developed. For the remote indicating instruments inverters were originally designed for 32 volts and 60 cycles. It was found possible to reduce the weight of this equipment considerably by operating the instruments at 120 cycles with a corresponding increase in voltage. The vibrating-switch type of inverter has proved successful for this application. It was necessary to provide adequate filtering to prevent radio interference and to redesign the electric circuit to insure the needed reliability. This type also has proved an excellent source of power for fluorescent lighting. For gyroscopic instruments, however, a higher frequency was needed. For reasons to be discussed later 400-cycle power is advantageous. The highest practical value thus far produced for vibrating-switch type inverters is 200 cycles. For this reason it appears that 400-cycle inverters must be rotating machines, which are being developed in ratings from 100 to 1,500 volt-amperes with efficiencies of approximately 75 per cent and weights from 8 to 20 pounds.

MOTORS

The principal items of equipment to receive power are electric motors of various types. Motors have been used for operation of such accessories as landing gear, flaps, pump units, valve mechanisms, etc. Their use as a continuously operating drive has come only in the last two years. The mechanical drives, such as landing gear and flaps, are intermittent-duty applications. Most of the pump drives are continuous-duty applications, although in such instances as propeller-feathering pumps the duty is intermittent. In the operation of de-icing equipment, electric motor drives have the greatest advantage. Operation of the de-icing air pumps from a mechanical drive on the main engine means that they will be operated con-

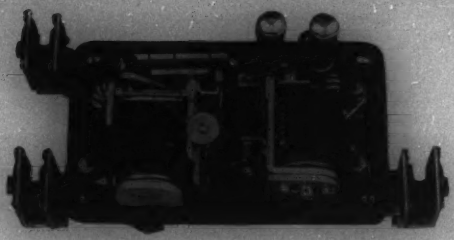

Figure 4. Control panel, 8 inches long, consisting of a voltage regulator and reverse current relay, for 50-ampere 15-volt engine-driven generator

tinuously although flight in de-icing conditions occurs during a very small portion of the time. When the pump is driven by an electric motor, it is used only when those conditions are encountered.

Electric motors for operation of fuel pumps are being developed at the present time and show much promise. For this application it is necessary to provide a motor of explosion-proof construction. In most cases these motors have been constructed to requirements of the Underwriters' Laboratories, but these have proved unnecessarily severe for aircraft duty. They are based on industrial practice and are intended for use with motors having a relatively large internal volume. For aircraft a motor necessarily must be as small and light as practicable. The imposition of bearing-length and flange-construction requirements necessary for industrial motors on aircraft motors which have a volume of only 1/100 of the equivalent industrial motor is unnecessarily severe. Research is being undertaken to determine more reasonable design characteristics so that explosion-proof construction will not make the weight and size of the motor prohibitive.

Some work has been done in recent years on the development of a motor which will transfer accurately a desired position of a driven device. Remote indicating instruments are representative of this type, but their characteristics are such that no usable torque other than movement of a needle can be transferred. A positioning motor is one that will deliver any desired amount of torque and position accurately a device at a remote location by the operation of some transmitting device at the pilot's cockpit. The simplest type of equipment for this purpose consists of a potentiometer at the pilot's control board and a motor at the driven device with a corresponding potentiometer. Setting the control potentiometer automatically causes the motor to start and drive the device and the second potentiometer in the proper direction again to neutralize the control voltage. This type of equipment has many applications, the largest of which is the landing flaps. With such a motor the pilot need only set a potentiometer at the position corresponding to the desired setting of the flaps, for example, 40 degrees, and the motor will start and drive the flaps to this position without further attention by the pilot.

Many types of motors are needed for aircraft. The landing gear and flap motors described are primarily torque motors designed for intermittent duty. For this application the series-wound motor has proved best. For continuous-duty applications with pumps, where speed regulation is an important characteristic, the shunt-wound motor is superior. Explosion-proof construction is required for motors used with fuel pumps and propeller anti-icing fluid pumps. In most cases the series-wound motors used with intermittent-duty applications must be designed for reversing. In the past this has been accomplished by use of two series fields. However, present indications are that the use of a double-pole, double-throw relay with a single-field motor will provide some saving in weight in the motor and considerable saving in weight of the wiring.

Curves showing the weights and efficiency of d-c motors to conform to Air Corps specifications are shown by figures 5 and 6. Similar curves for a-c motors are shown by figures 7 and 8. As motors have been procured which exceed the performance and weights required by these curves, they are believed to be quite conservative. Points which represent such motors are plotted on these figures and connected to the corresponding point which represents Air Corps requirements. An interesting point with regard to the operating speed of a-c motors can be noted from figure 3. A motor operating at 24,000 rpm and designed for only intermittent duty weighs only one-half as much as a motor designed for continuous duty at a synchronous speed of 4,000 rpm. Therefore, the increase in speed of 6 to 1 has resulted in a saving of weight of less than 2 to 1. For this reason, further applications of a-c motors will discourage the use of excessive speeds with their problems of lubrication and life. It is entirely practicable to construct an a-c motor for continuous duty at 12,000 rpm, which will have an operating life of 1,000 hours. At the present time it is considered to be impracticable to accomplish the same result at 24,000 rpm.

DISTRIBUTION SYSTEM

Problems involved in the electrical distribution system can cause excessive costs, production delays, and unreliable performance, unless they are carefully controlled. The cable normally used in Army aircraft wiring for distribution of electric power requires two layers of varnished cambric, oppositely wound, covered with varnish-impregnated fabric. The weight and size of this cable are shown by table III. The gauge size is AWG. The

Table III. Weight and Size of Cable

Gauge	Diameter		Weight (Pounds Per Foot)	Rating
	Over-all	Conductor		
22	0.090	.032	0.003	1
20	0.126	.041	0.006	2
18	0.136	.050	0.009	5
16	0.146	.060	0.012	10
14	0.166	.080	0.018	16
12	0.186	.100	0.026	23
10	0.208	.120	0.054	35
8	0.250	.150	0.090	45
6	0.300	.190	0.110	65
4	0.370	.240	0.180	90
2	0.440	.300	0.238	125
0	0.525	.380	0.360	200

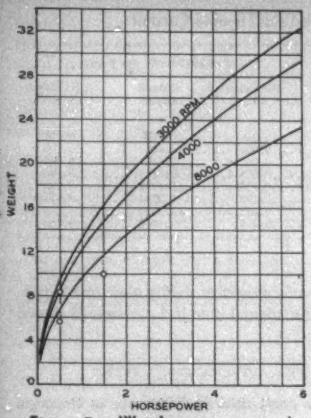

Figure 5. Weight versus power, d-c motors

$$Wt = \left(12\sqrt{hp} \times \sqrt[3]{\frac{4{,}000}{\pi}}\right) + 0.1$$

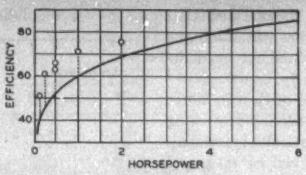

Figure 6. Efficiency versus power, d-c motors

$$Eff = \sqrt[4]{hp} \times 60$$

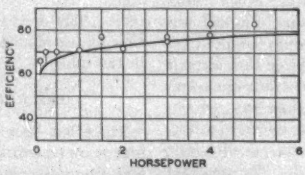

Figure 7. Efficiency versus power, a-c motors

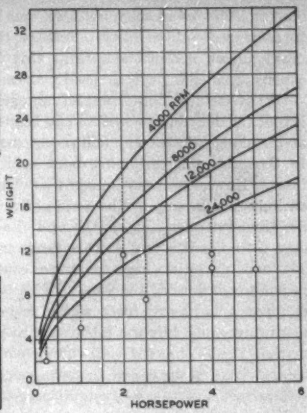

Figure 8. Weight versus power, a-c motors

weight per foot of the cable is tabulated, as is the current rating normally permitted.

The size of cable used for an individual circuit depends upon the length of that circuit. Normally, continuous-duty loads are required to have a voltage drop of less than three per cent. The maximum current permitted in a given size of conductor is that tabulated in table III. These currents may be doubled if the duty is intermittent. The insulation required on this cable is adequate for any voltage heretofore used in aircraft for power, and is required more for mechanical protection than for its insulation properties. For this reason the same cable has been used in 12-, 24-, and 110-volt electrical systems. The minimum size of cable is determined by its mechanical strength. For many years a size smaller than number 18 was not permitted, because pulling cable through conduit broke smaller sizes. Number 20 has been permitted in recent years. Number 22, referred to in table III, is a special cable using rubber insulation which is permitted only in instrument-lighting circuits where the conduit run is very short.

The methods used to reduce radio interference with the electrical distribution system have been based upon insufficient understanding of the problem. Radio interference is a quantity which is very difficult to measure and which probably has been given undue consideration. In the past the practice of the aviation industry has been to require as nearly perfect electrostatic shielding as can be incorporated in the airplane, and that this shielding be bonded to the structure as often as practicable. The resulting installation is heavy, difficult to install, and consequently very expensive. The shielding usually has been provided by a system of conduit, both rigid and flexible, in combination with aluminum boxes. Table IV shows the weight characteristics of various types of flexible conduit. This conduit usually consists of aluminum alloy armor covered by a woven braid of aluminum alloy or tinned copper wire. In case resistance to moisture is important, this conduit may be obtained with a thin coating of rubber. The increase in weight caused by the conduit can be estimated by assuming that the weight of tinned copper conduit approximately equals that of the wiring which it encloses. The weight of wiring in typical airplanes is given in table V.

Radio-equipment manufacturers have made no effort to shield their equipment in a way that takes advantage of the all-metal aircraft structure. Proper shielding of the antenna lead-in and radio equipment, with use of the airplane structure to shield interference originating within the fuselage, would seem to be entirely practicable. The metal structure of fuselage and wings would take the place of the aluminum conduit now used, and it would be necessary to provide conduit as a means of mechanical support only. From 900 to 2,000 bonds are now required to ground the shielding system, as well as parts of the airplane structure. As the engineering and installation costs of these bonds may be approximately $1 each, a considerable saving can be achieved simply by reducing their number.

While the requirements for radio performance in aircraft must be high on account of the great range in frequency and distance, there is considerable reason to doubt the necessity for the elaborate installations which have been made in the past. It is hoped that, with improvements in radio equipment and filtering, the electrical system in the airplane can follow automotive practice more closely than heretofore.

Another problem encountered primarily in military aircraft is that of vulnerability of the electrical system. A group of circuits confined in one conduit for the purpose of reducing radio interference and mechanical support is a highly vulnerable target. For that reason, military air-

craft is likely to sacrifice freedom from radio interference to decreased vulnerability. Perhaps this will force the development of radio equipment that does not need the expensive shielding system used previously.

One of the most important advantages of electric power is that the distribution system can be made self-protecting and so designed that any failure automatically is isolated. In the past, this result has been achieved by means of fuses. However, the equipment available thus far is not entirely satisfactory. The automotive-type fuses which use tinned copper clips on the end of a glass or phenolic case do not withstand service usage as well as desired. The clips develop a high resistance contact which causes premature failure of the fuses. This type of failure was eliminated by using fuses which had lugs adapted for mounting studs, but the fuses were so large that aircraft manufacturers objected. Circuit breakers have been considered for this duty, but to date none has been demonstrated which satisfactorily duplicates the action of a fuse.

For control of the distribution system, small toggle switches and relays are normally used. The switches occupy a space approximately 2 inches long by 3/4 inch wide by $1\frac{1}{4}$ inches deep. These are available in both single- and double-throw designs and with a variety of operational combinations. Relays suitable for use in aircraft are scarce. Relays are not justified until the circuit load exceeds 25 amperes. Commercial relays designed for currents between 25 and 200 amperes are much larger than necessary. In addition, they must be designed to withstand vibration, temperature, altitude, and other characteristics of use in aircraft.

The distribution of cable in three sizes of aircraft is shown by table V. Reference to this table shows that most of the cable in use is in the smaller sizes, 16 to 20. The total weight of the respective sizes for the size of airplane under consideration is also tabulated. While a great length of cable is used in the smaller sizes, the weight of the larger sizes exceeds that of the smaller. This demonstrates most effectively the advantage of higher operating voltages. All the airplanes for which consideration is given in table V have 12-volt electrical systems. The decrease in weight of wiring alone made possible by use of an equivalent 110-volt d-c system is shown in the table.

Table IV. Flexible Conduit

Size in Inches		Weight (Pounds Per Foot)		
ID	OD	Aluminum Alloy	Tinned Copper	Rubber Covered
1/4	0.390	0.048	0.0717	0.154
3/8	0.515	0.065	0.0871	0.193
1/2	0.640	0.084	0.1130	0.242
5/8	0.765	0.098	0.1428	0.280
3/4	0.920	0.130	0.1832	0.380
1	1.210	0.193	0.2745	0.514
$1\frac{1}{4}$	1.463	0.233	0.3524	0.638
$1\frac{1}{2}$	1.716	0.278	0.4700	0.750

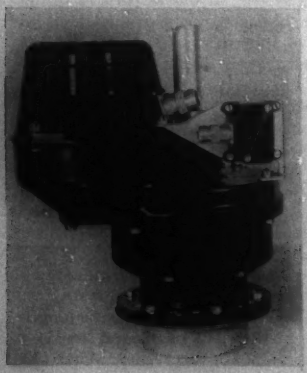

Figure 9. A-c engine starter designed for use with 110-volt three-phase 400-cycle power

A flywheel, of which the rotor is a part, is accelerated to 12,000 rpm, when the energy thus accumulated is released through a clutch to the engine crankshaft

DIRECT VERSUS ALTERNATING CURRENT

There has been a great deal of discussion in the past four years regarding the comparative advantages of direct and alternating current for use in aircraft. D-c power can easily provide a reservoir of energy in the form of a battery and its use is comparatively familiar, since the system is very similar to that used in the modern automobile. As to disadvantages, d-c systems which use a battery are practically confined to a relatively low voltage, which means a heavy distribution system. The use of low voltage places a definite limit on available power, since conductors which carry more than 200 amperes continuously without excessive voltage drop are too heavy to be of any value in aircraft. The question of commutation at altitude has not been completely decided. It is known that arcing, which is practically negligible at sea level, becomes a serious matter in the ionized air of the substratosphere. Whether this is a serious condition has not yet been determined. The weight of d-c equipment is somewhat greater than that of the a-c equipment of the same power and speed. Likewise, the efficiency is lower.

A-c power has the advantages of light weight and flexibility of voltage. The latter is of particular importance to manufacturers of radio and lighting equipment. Some prospective users of a-c power have cited as an objection the fact that the high frequency will cause a noticeable hum in radio-receiver equipment. That this need not occur has been proved by the Army Air Corps with use of both 800- and 400-cycle equipment and by the commercial aviation industry with 800-cycle equipment. In each case it was found very easy to filter out the a-c hum. The filters were more easily constructed than equivalent filters to reduce the noise caused by d-c commutation. The higher voltages readily obtained with a-c generators permit a greater application of small-cable sizes, thereby greatly reducing the weight of the distribution system. The elimination of commutators increases the safety of the system, particularly when used with fuel pumps, and increases the operating life of equipment. Practically no maintenance will be needed for a-c motors and transformers, except lubrication of the motors, whereas brush-life as well as lubrication determines the operational periods for d-c motors and dynamotors.

Table V. Distribution of Cable in Three Sizes of Aircraft

Size AWG	Single Engine				Two Engine				Four Engine			
	No. Pieces	Length Feet	Weight (Pounds) 12 Volts	110 Volts	No. Pieces	Length Feet	Weight (Pounds) 12 Volts	110 Volts	No. Pieces	Length Feet	Weight (Pounds) 12 Volts	110 Volts
0	6	25	9.0		14	99	36					
2	4	6	1.4		5	39	9.3		62	430	102	
4	4	10	1.5						3	70	12.6	
6	10	40	4.4		14	124	13.7		34	334	36.6	
8	14	88	7.9		11	48	4.3		24	185	16.7	
10					42	299	16.2		8	70	3.8	
12	54	385	10.0		4	33	0.9		53	384	10.0	
14				0.6	7	55	1.0	2.5				7.8
16	55	585	7.0	0.6	193	1,524	18.3	1.5	140	1,660	19.9	4.9
18	7	45	0.4	0.6	113	761	6.9	4.0	345	2,990	27.0	5.8
20	101	578	3.5	7.2	202	2,265	13.6	27.3	2	8	0.1	23.0
22	4	7	0.1	0.1	42	222	0.7	0.7	291	4,760	14.3	14.3
Total	258	1,769	45.5	9.1	647	5,469	120.9	36.0	962	10,891	243.0	60.8

When considering alternating current for use in aircraft, frequency and number of phases as well as operating voltage must be decided. For the past five years the Army Air Corps has conducted a development program, during which frequencies of 60, 180, 240, 360, 400, and 800 cycles were considered. Equipment at frequencies of 360, 400, and 800 cycles was tested. It was found that the weight of such equipment as motors and transformers reaches a practicable minimum at approximately 240 cycles per second. The gain made by going to still higher frequencies is partially offset by the increase in iron necessary to decrease hysteresis losses. The selection of a suitable frequency, if the value is to be above 240 cycles, depends upon characteristics other than weight, the most important of which is the operating speed of alternators and generators. As noted, an operating speed of 24,000 rpm appears to be impracticable, for continuous-duty motors, but practicable for intermittent-duty motors. Therefore, the minimum frequency to be considered is 400 cycles. Tests with 400- and 800-cycle equipment showed little difference. However, the speeds available with 800 cycles are 48,000, 24,000, 16,000, 12,000, etc., to a practical minimum of 6,000 rpm. The speed for 400-cycle motors ranges from 24,000 to 3,000 rpm. As this appeared a more useful range of speed, the Army Air Corps has standardized on 400-cycle frequency for a-c power, in case it is used.

Tests also were made with both single- and three-phase systems. The single-phase system has the advantage that the distribution system requires only two cables, or one cable and a ground return. The three-phase system requires three smaller cables, or two and a ground return, and has the additional disadvantages that phases must be balanced within reasonable limits and that the power factor is lower. In so far as motor characteristics are concerned, a single-phase motor must use a split-phase winding supplied through a capacitor or resistor. The weight of this capacitor offsets the savings in wiring possible with the single-phase system. For reversing motors, the wiring system to a single-phase motor is actually heavier than that to a three-phase motor, since three large cables are used instead of three small ones.

The matter of paralleling the output of a-c accessory power plants is an important consideration, since the entire output of all accessory power plants must be available during certain conditions of flight. Parallel operation was not satisfactorily accomplished between single-phase alternators, while it was with three-phase alternators.

A-c aircraft power, in so far as military applications are concerned, has a doubtful status at the present time, due to the deficiencies in small engines for operation at altitude already mentioned. Since separate prime movers are impractical for use at high altitudes, the main engines on the airplane must be relied upon as a primary source of power. These engines must be operated at a variable speed, a condition which prevents any consideration of direct-driven alternators as a source of electric power. While it would be possible to utilize separate alternators with a divided bus to permit distribution of power from any alternator to any load, this installation would be more difficult than is desired. However, the successful development of a constant-speed drive which could be driven by the variable-speed main engine would permit the use of a-c power in medium and large aircraft. This constant-speed drive must be reasonably light in weight and of such accuracy that parallel operation between alternators can be obtained. To provide the equivalent of a battery for starting the main engines, an accessory power plant, to be used only on the ground for starting the main engines and for ground power, would be installed in each airplane.

One possible source of electric power not yet developed by the electrical industry is a variable-speed alternator operating with a rectifier to duplicate the present d-c generator. A 100-ampere 30-volt generator now weighs 32 pounds. The regulator and reverse current cutout used with this generator weigh another 4 pounds, making a total of 36 pounds. An equivalent variable-speed alternator and rectifier with controls in approximately this weight would have several advantages to justify its use. Voltage regulation would be a simpler matter, commutation would be eliminated, and radio interference would be reduced to an almost negligible amount.

Summarizing the situation with regard to electrical applications in aircraft, it is hoped that the electrical industry will take an increased interest in providing more suitable equipment to meet the special needs of the aviation industry.

Institute Activities

Attractive Features Arranged for Summer Convention at Toronto

THE AIEE summer convention, to be held in Toronto, Canada, June 16–20, 1941, offers members and guests unusual opportunities to combine business and pleasure. The technical program, which is scheduled to appear in the June issue, will include outstanding papers on a variety of timely subjects, as well as technical conferences and committee meetings. United States visitors, their Canadian hosts claim, will find novel touches in the entertainment, unusual opportunities to make their stay in Canada a high spot among long-to-be-remembered holidays. Sports and entertainment programs are now complete. Extensive plans have been made for the special benefit of women guests. Convention headquarters will be in the Royal York Hotel. No difficulties will be experienced in crossing the Canadian border (*EE, March '41, p. 134*).

Canadian AIEE members hope to make their guests feel so much at home that they will want to stay long after the convention is over, and return each year to renew acquaintances. The Mayor of Toronto, the Premier of Ontario, and the Prime Minister of Canada all have extended official and formal welcome to the AIEE. There remains, however, the unofficial and informal welcome for which Canada is noted.

For a city of over 850,000 population Toronto has exceptional facilities for enjoyment. Fourteen miles of lake front add an unusual summer-resort atmosphere to the service and comfort found only in large centers. At Sunnyside, one of the near-by beaches, is a most attractive amusement park. Closer still to convention headquarters are the Canadian National Exhibition grounds, 350 acres of landscaped park, and a mile and a half of Lake Ontario's waterfront. The exhibition buildings are now occupied by soldiers and airmen, but the grounds are open to visitors. Also near convention headquarters is old Fort York, built in 1793, a vivid reminder of the rivalries and contests of the past. Just two or three blocks from headquarters are two of the largest department stores in the world, as well as unusual specialty shops—always an attraction for women guests.

Only a few hours by train or automobile from Toronto in almost any direction will bring the visitor to vacation lands with clear sunlit waters and pine-fringed islands, where he may paddle a canoe, race a motor launch, sail a boat, or enjoy numerous steamer trips. Varied accommodations are available at hotels, camps, bungalows, or lodges. In the higher altitudes north of Toronto, hay fever is unknown.

East of Toronto, and reached by a beautiful drive along Lake Ontario, is the famous Thousand Island section of the St. Lawrence River. Just north of this are the picturesque Rideau Lakes. About 50 miles north of Toronto is Lake Simcoe. East of Lake Simcoe are the Kawartha Lakes and to the west is sheltered Georgian Bay with its many miles of sandy beaches and its surprisingly warm water. Another two-hour drive brings the vacation-bound visitor to the Muskoka Lakes and the Lake of Bays. Especially noted for fishing these districts also provide facilities for golf, tennis, swimming, and boating.

INSPECTION TRIPS

Advance registration for inspection trips is absolutely essential because of national-defense requirements. The trips committee has made strenuous efforts to provide a large variety of excursions.

Probably one of the most popular trips will be that scheduled for Thursday afternoon to the Toronto-Leaside 220-kv transformer station of the Hydro-Electric Commission of Ontario. Located on the outskirts of the city, some seven miles from convention headquarters, this is one of two receiving terminal stations of the Hydro's 220-kv system. The initial components of the station were placed in service in 1928.

Tentative Schedule of Events

Sunday, June 15

4:15 p.m. English tea party

Monday, June 16

9:00 a.m. Registration
9:30 a.m. Instruments and measurements
9:30 a.m. Communication
1:30 p.m. Qualifying round for Mershon and Lee trophies
2:00 p.m. Conference of officers, delegates, and members
9:00 p.m. President's reception

Tuesday, June 17

9:00 a.m. Registration
10:00 a.m. Annual meeting
12:30 p.m. Luncheon
1:30 p.m. First round, Mershon trophy
Second round, Lee trophy
2:00 p.m. Conference of officers, delegates, and members (continued)
2:00 p.m. Conference of Branch counselors
9:15 p.m. Hart House party

Wednesday, June 18

9:00 a.m. Registration
9:30 a.m. Basic sciences and electronics
9:30 a.m. Land transportation
9:30 a.m. Switching equipment
12:30 p.m. Board of directors' luncheon and meeting
1:30 p.m. Second round, Mershon trophy
2:00 p.m. Electrical machinery
2:00 p.m. Relays, lightning, and insulation

Thursday, June 19

10:00 a.m. General session
10:30 a.m. Semifinals, Mershon trophy
2:00 p.m. Industrial power applications
2:00 p.m. Power transmission
2:30 p.m. Finals, Mershon trophy
7:30 p.m. Annual dinner (summer formal)
9:00 p.m. Dance (summer formal)

Friday, June 20

9:30 a.m. Power generation
12:30 p.m. Luncheon, presentation of sports prizes
2:00 p.m. Conference on domestic and commercial applications
2:00 p.m. Standards conference

Some Summer-Convention Attractions

Pictured on the facing page are some of the features in and near Toronto included in inspection-trip and entertainment plans.

1. **Looking down the transformer runway, Toronto-Leaside station, at 420,000 kva of installed capacity**
2. **New Millwood Road residential substation of the Toronto Hydro-Electric System**
3. **Royal Canadian Yacht Club, Centre Island**
4. **Royal Ontario Museum, Toronto**
5. **Circuit breaker assembly, Canadian Westinghouse Company, Ltd.**
6. **Glengrove substation, Toronto Hydro-Electric System, 25,000 kva, supervisory controlled, is located in a residential district**
7. **Transformer banks at the rear of the Glengrove station**
8. **Unit substation, 26,400-volts, forming part of the primary network of the York Township Hydro-Electric System**
9. **Core and windings for a 25,000-kva outdoor transformer being lowered into the vacuum drying and oil-impregnation tank at the Toronto Davenport works of Canadian General Electric Company. The transformer will be installed in the new Burlington station of the Hydro-Electric Power Commission of Ontario**

Annual Meeting

The annual meeting of the American Institute of Electrical Engineers will be held at the Royal York Hotel, Toronto, Ont., Canada, at 10 a.m. on Tuesday, June 17, 1941. This will constitute one session of the summer convention.

At this meeting, the annual report of the board of directors and the report of the committee of tellers on the ballots cast for the election of officers will be presented.

Such other business, if any, as properly may come before the annual meeting may be considered.

(*Signed*) H. H. HENLINE
National Secretary

since which time it has been expanded to its existing capacity of 420,000 kva. Three 220-kv circuits enter and one leaves the station, on four-circuit bridge-type structures on a 200-foot-wide right of way. Six banks of 45,000-kva and two banks of 75,000-kva three-winding transformers are installed. Four 25,000-kva vertical-shaft outdoor synchronous condensers also are installed.

Perhaps of still greater interest will be the Hydro-Electric Power Commission's new 220-kv receiving terminal now nearing completion of the initial installation. It is located some 40 miles west of Toronto on the Queen Elizabeth Way. Known as the Burlington transformer station, this new receiving terminal has an initial installation of two incoming 220-kv circuits and two banks of 75,000-kva forced air-cooled transformers. The station is designed for an ultimate installation of 450,000 kva. The 220-kv transmission extension of the Commission, around the metropolitan area of Toronto and west to Burlington, is of double-circuit construction, utilizing type *HH* segmental-copper conductors. Arrangements will be made to inspect this new construction as part of the Burlington trip.

For communications men, there will be a trip to the Bell Telephone automatic exchange and a specially arranged communications trip including radio station CBL, Hornby repeater station, and the Trans-Canada Airways beacon and airport facilities, both on Tuesday, June 17. A special trip for distribution men will include the low-voltage network of the Toronto Hydro-Electric System, also a tour of the recently completed primary network of York Township Hydro, as well as visits to a newly completed residential substation of the Toronto Hydro, and another to the Glengrove Avenue substation. A trip is also arranged to the Hillcrest shops of the Toronto Transportation Commission.

Of special interest also are organized trips to the Hydro-Electric Power Commission's laboratories, an inspection of the Commission's network calculator, and an evening trip (on Wednesday, June 18) to the Dunlap Observatory.

Efforts will be made to arrange trips to a number of manufacturing plants in Toronto, Hamilton, and Oshawa. These trips, of course, must be governed entirely by national-defense regulations in force at the time of the convention, but if advance registration indicates sufficient interest, the trips committee will try to arrange visits to such of the following plants as are of particular interest to visitors: Canada Wire and Cable Company, Ltd.; Canadian Westinghouse Company, Ltd.; Steel Company of Canada; Otis-Fensom Elevator Company; Ferranti Electric Company; Canadian General Electric Company, Ltd., transformer plant, and others.

ENTERTAINMENT

Members are urged to travel to Toronto over the week-end in order to attend the first get-together on Sunday afternoon. This will be an English-style tea party, to be held in the Palm Court of the Royal York Hotel, commencing at 4:15 p.m. The Royal York String Orchestra with additional artists will be in attendance. No charge will be made for attending members and their guests.

On Monday, June 16, the president's reception will be held at 9:00 p.m. in Room A of the Royal York, to be followed by an informal dance in the Concert Hall. As part of the entertainment after the dance, uniformed pipers will parade through the Concert Hall accompanied by dual flag bearers who will sing the British and United States national anthems. A buffet supper will be served at 11:30 p.m. Card playing will be arranged for in the anteroom. No charge will be made for the evening's entertainment.

On Tuesday, June 17, an organized luncheon is planned (tickets $1.00 each), to which women guests will be invited. At 9:15 Tuesday evening, members and guests will travel through the city to the University of Toronto's famous Hart House which has been turned over completely to the AIEE for the evening. Here a series of entertainment features will be presented from opening time until 12:30 a.m. Heading the list will be two stage performances in Hart House theater, one running from 9:30 p.m. to 10:15 p.m. and the other from 10:45 to 11:30. The Hart House carillon will be played by Leland Richardson during the period while guests are arriving. Several novel entertainment features will run concurrently with the main shows. The Toronto Dolphinettes will present a display of swimming and diving; a series of badminton games will be in progress in the upper gymnasium; a series of ten-minute musical recitals will be given in the music room; and other features are planned, including moving pictures presented by the Hydro-Electric Power Commission of Ontario, a marionette performance, and exhibition games of squash. There will be continuous dancing from 9:30 p.m. until 1:00 a.m. in the big gymnasium with an intermission during which Chinese performers will give the dragon dance. Weather permitting, those who prefer may wander out to the Quadrangle which will be suitably lighted. Tables and chairs will be placed there, under the open sky, punch will be served, and a trio of troubadours will be in attendance. A buffet supper will be served in the Great Hall. Tickets for the evening's entertainment will be $1.00 each.

The formal dinner and dance will be held in the Banquet Hall of the Royal York Hotel on Thursday, June 19. Tickets for the dinner are $1.50 each and for the dance $2.00. At 10:30 p.m. there will be an intermission of 15 minutes for a parade of a pipers' band in full-dress uniform, and other entertainment features. A buffet supper will be served at 11:30 p.m.

On Friday, June 20, there will be an organized luncheon in the Roof Garden, at which the sports prizes will be presented. Luncheon tickets will be $1.00 each.

SPORTS

Excellent facilities for practically all types of sport abound in and around Toronto. The term "golfers' paradise" has been applied to the city, and in addition there are ample facilities for tennis, aquatic sports, and many other types of outdoor activity. All golf events for men will be played at the Weston Golf and Country Club. Arrangements may be made with any member of the committee or at the registration desk for noncompetitive play on several other Toronto courses.

The qualifying round for the Mershon and Lee trophies will be played on Monday afternoon. The second 18-hole round for the Lee trophy will be played on Tuesday and in case of a tie an additional 18 holes will be played on Wednesday. The first round of match play for the Mershon trophy is to be played on Tuesday, the second round on Wednesday, and the third on Thursday morning, with the final round Thursday afternoon.

In addition to these annual competitions, there will be a District team competition in which each District may enter a team of four men. Then there is to be a "kicker's handicap" (blind bogey) event.

The Mershon tennis tournament for men will be played at the Boulevard Club on Toronto's lake shore, on the afternoons of June 16–19 from 2:00 to 5:30 p.m. The finals will be held on Thursday afternoon.

Women's golf events will be played at the Toronto Ladies' Golf and Country Club at Thornhill. Prizes will be provided for all competitions. Women wishing to compete should make their desire known at the women's committee desk at the time of registration. Courts will be available in the mornings at the Boulevard Club for women wishing to play tennis.

WOMEN'S ENTERTAINMENT

In planning entertainment the committee in charge assumed that women guests would prefer to have mornings relatively free to play golf or tennis, visit Toronto's shopping district, or follow other individual inclinations, without missing the prearranged events. The evening events are being held jointly for men and women. During the afternoons the following entertainment has been planned especially for the women and is complimentary to those wearing AIEE badges.

Monday, June 16. At 2:30 p.m., busses will leave the Royal York for a visit to the James Gardens in one of Toronto's fine residential suburbs, to be followed by a visit to the Old Mill tea gardens. The stone house on the F. T. James Estate stands on an escarpment overlooking the Humber Valley. In the natural sunken gardens, luxurious blue spruce trees form backgrounds for lawns and pools and exquisite flowers. Winding paths lead down through rock gardens and natural woods to the river. The Old Mill,

Some Toronto Hotels and Rates

Hotel	Single*	Double*	Single With Bath	Double With Bath
Royal York (headquarters)			$4.00	$6.00
King Edward			3.00 to $5.00	6.00 to $8.00
Prince George	$2.00	$3.00 to $3.50	2.50 to 3.00	4.00 to 5.00
Walker House	2.00	3.50	3.00	4.50 to 5.00

* Without bath but with running water.

where tea will be served, has a rich historical background. When the first white men came to Canada the Humber River was a well-known Indian pathway from Lake Huron to Lake Ontario. Today the ruins of the Old Mill, built on the Humber in 1798, can still be seen, and a visit to the Old Mill restaurant presents an opportunity for inspection of the many relics gathered together there.

Tuesday, June 17. Busses will leave the Royal York at 2:30 p.m. for Eaton's College Street store where a fashion show will be presented. Tea will be served, and may be followed by a tour through the store.

Wednesday, June 18. At 1:30 p.m., buses will leave the Royal York to take women guests to the Royal Canadian Yacht Club wharf, from where they will proceed by pinnace to the Royal Canadian Yacht Club on Toronto Island across the bay from the city. Those who wish may spend the afternoon at the Yacht Club for bridge and tea, and those not wishing to play bridge may enjoy a short launch cruise through the island lagoon.

Thursday, June 19. A conducted tour via the University of Toronto grounds and Parliament buildings to the Royal Ontario Museum, where they will be conducted through the sections in which they are especially interested. Because the Royal Ontario Museum is so vast (having five acres of galleries) it is impossible to see the whole museum in one attempt. Accordingly, to permit seeing the parts of most interest, guests will be urged to indicate their preference at the women's registration desk not later than Thursday morning. Included in the museum is a Chinese section, acknowledged to be one of the world's best, along with other sections devoted to pottery, dresses, furniture, gems, wild life in Canada, murals and panels illustrating the stages of the earth's evolution. Tea will be served in the garden.

HOTELS AND REGISTRATION

Members should make their hotel reservations by writing directly to the hotel preferred. For convenience, the rates of the headquarters hotel, the Royal York, and several other Toronto hotels are given in the accompanying table.

Members who will attend the convention should register in advance by filling in and mailing the advance registration card when received with the mailed announcement. This will assist the committee in making advance arrangements and minimizing congestion at the registration desk. A registration fee of $2.00 will be charged all nonmembers except Enrolled Students and the immediate families of members.

SUMMER CONVENTION COMMITTEE

M. J. McHenry, *chairman;* A. H. Frampton, *vice-chairman;* D. G. Geiger, *secretary;* C. E. McWilliam, *treasurer;* A. W. Bradt, C. H. Burchill, E. V. Caton, R. B. Chandler, K. V. Farmer, W. G. C. Gliddon, H. W. Habert, G. R. Langley, J. H. Steede, and B. J. O. Strong. *Subcommittee chairmen:* M. J. McHenry, *finance;* T. W. Hill, *publicity;* W. J. Gilson, *entertainment;* T. W. Eadie, *sports;* J. F. Neild, *transportation;* V. G. Smith, *trips;* F. F. Ambuhl, *hotel and registration;* O. W. Titus, *women's entertainment;* J. W. Barker, *technical program;* O. W. Titus, *local representative, technical program;* M. S. Coover, *Sections;* and J. M. Thomson, *local representative, Sections.*

Pacific Coast Convention to Be Held at Yellowstone Park

The wonders of Yellowstone National Park will provide the setting for the AIEE Pacific Coast convention, to be held August 27–29, 1941. The Canyon Hotel, headquarters for the convention, is near the Great Falls of the Yellowstone, pictured on this page at the point where the canyon walls show the brilliant color that gave its name to Yellowstone Park, River, and Lake. The rocks are radioactive.

AIEE members and their families also may see Yellowstone's two groups of geysers and colored hot pools, and many miles of rugged scenery along paved safe highways. Along the roadside will be seen wild bear, pronghorn antelope, moose, elk, and deer. By going back farther, and having luck, the visitor may find beaver, buffalo, geese, mountain sheep, and rare swans. No fishing license is required in the Park, the streams of which are stocked afresh each year.

Especially for those driving to the convention, trips can be arranged to include rugged Glacier Park, several major hydroelectric plants, Fort Peck Dam, rodeos, Indian Reservations, little-known Morrison Cave (third largest in the United States), mines and smelters, and historical spots at Virginia City, Bannock, and several Indian battlefields. Further information may be obtained from the convention publicity chairman, Clair F. Bowman, Helena, Mont. Inspection trips will be announced in a subsequent issue. W. A. Boyer is chairman of that committee.

Future AIEE Meetings

Summer Convention
Toronto, Canada, June 16–20, 1941

Pacific Coast Convention
Yellowstone National Park, August 27–29, 1941

South West District Meeting
St. Louis, Mo., October 8–10, 1941

Southern District Meeting
New Orleans, La., December 3–5, 1941

Winter Convention
New York, N. Y., January 26–30, 1942

Methods of Mathematical Analysis to Be Published

"Advance Methods of Mathematical Analysis as Applied to Electrical Engineering" is the general title covering a symposium of five lectures given in New York between December 5, 1940, and April 2, 1941, under the sponsorship of the basic sciences group of the New York Section AIEE. Designed to acquaint the average engineer with the general principles (simplified and co-ordinated) involved, these lectures were received so enthusiastically that they currently are being developed into manuscript form for publication in ELECTRICAL ENGINEERING, perhaps beginning early this summer.

The following listing covers the intended subjects and authors:

1. Heaviside's Direct Operational Calculus, Professor J. B. Russell, Columbia University.

2. Integration in the Complex Plane, Professor Kurt O. Friedrichs, New York University.

3. Circuit Analysis by Laplacian Transforms, Doctor J. Millman, College of the City of New York.

4. Analysis of Systems by Fourier Integrals, Professor W. L. Sullivan, Stevens Institute of Technology.

5. Traveling Waves on Transmission Lines, Professor R. Weber, Polytechnic Institute of Brooklyn.

New Technical Committee Appointed

At its meeting January 30, 1941, the AIEE board of directors voted to establish a new technical committee on applications of electricity to therapeutics. The scope of the new committee will be decided upon by the members and the technical program committee, but in general it is planned to include all applications of electricity pertaining to health, such as sanitation, sterilization, and radiation.

Members of the new committee are:

Lloyd L. Call, *chairman*, General Electric X-Ray Corporation, 2012 Jackson Boulevard, Chicago, Ill., C. V. Aggers, W. D. Coolidge, Harvey Fletcher, Roy Kegerreis, and W. B. Kouwenhoven.

No Fortescue Fellowship for 1941–42

The Charles LeGeyt Fortescue Fellowship committee, meeting March 31, 1941, voted not to award the fellowship for the year 1941–42, "in view of the national emergency and the limited number of candidates making application." Announcement that applications were open appeared in the January issue, page 31.

The demand for young men in industry and military service resulting from the national emergency was considered by the committee to be the chief cause for the small number of applications received. The consideration that the funds of the fellowship might prove more valuable in helping young men readjust to normal industrial life at the end of the emergency also was a factor in the committee's decision to make no award for the present year.

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained by mail by remitting price indicated to the AIEE order department, 33 West 39th Street, New York, N. Y.; or at five cents less per copy if purchased at AIEE headquarters or at AIEE convention or District-meeting registration desks.

The papers previewed in this issue will be presented at the AIEE summer convention, Toronto, Canada, June 16–20, 1941.

Basic Sciences

41-96—Measurement of Prebreakdown Currents in Dielectrics With a Cathode-Ray Tube; *H. H. Race* (*F'39*). *15 cents by mail.* In order to obtain more information regarding the mechanism of electrical breakdown in insulating liquids, a number of experimenters have studied current flow as a function of applied voltage, using high sensitivity d-c amplifiers with indicating instruments having relatively long time constants. Such instruments will not follow rapid changes in current where the time intervals are of the order of milliseconds or less. We investigated the possibility of using a cathode-ray tube as a current detector to follow current changes just preceding breakdown. This paper describes current measurements in liquids with 200-microsecond impulse voltage waves and current measurements in liquids and solids with gradually increasing unidirectional voltage applied to the specimens. In liquids, the evidence so far obtained leads to the tentative conclusion that the final breakdown current increases from a substantially steady value to failure in fractions of a microsecond. This indicates that the final breakdown mechanism is electronic. It appears also that the prebreakdown ionic current may be unrelated to the breakdown electronic current, since the breakdown gradient appears to be affected more by the electrode surface conditions than by the ionic conductivity of the liquid. In polystyrene and polyvinyl formal only one record was obtained showing any prebreakdown current greater than 10^{-8} amperes up to within 2 milliseconds of failure at breakdown gradients of the order of 2.5×10^6 volts per centimeter.

41-103—A Short Method for Evaluating Determinants and Solving Systems of Linear Equations with Real or Complex Coefficients; *Prescott D. Crout. 20 cents by mail.* This paper describes without proof a short method for solving arbitrary systems of linear algebraic equations, and evaluating determinants, the quantities involved being either real or complex. The work consists largely in determining an "auxiliary matrix," or block of numbers, the process being particularly adapted for use with a computing machine. The setting down of this matrix and of the final results is the only writing required. The work is cut almost in half if the given equations (or determinant) are symmetrical. A "check column" may be used if desired. The method described is much shorter than Gauss' method even when there is symmetry and the coefficients are real, in which case Gauss' method has been considerably refined by Doolittle. (Gauss' method is much shorter than a solution by determinants.) The process is applicable to the general case of m equations in n unknowns.

Industrial Power Applications

41-99—A New Mercury Rheostatic Element for Regulation and Control; *K. A. Oplinger* (*M'39*). *15 cents by mail.* This paper describes the principal design features and several typical applications of a new type of rheostatic device. The rheostatic member consists of a large number of hermetically sealed mercury contacts which can be operated by a small force and movement. A 100-step unit capable of controlling six kilowatts is described which is adaptable to many types of regulating systems. An electromagnetic driver operates the rheostatic member. Power amplification of the order of 100,000 can be obtained with the device.

Land Transportation

41-100—Glass-Bulb Mercury-Arc Rectifiers for Traction Service; *Charles E. Woolgar. 15 cents by mail.* The paper gives a general survey of the ability of glass-bulb mercury-arc rectifiers satisfactorily to meet the stringent requirements of traction service. Major features pertaining directly to glass bulbs are discussed, such as plant capacity, maintenance, efficiency, robustness, etc., but no attempt is made to include wider problems common to mercury-arc rectifiers as a class. Wherever necessary, comparison has been made to characteristics and behavior of other types of conversion equipment to indicate in what degree glass-bulb rectifiers meet the special requirements of traction service. Typical glass-bulb rectifier ratings, for example, efficiency, power factor, regulation, and overload capacity have been given without comment, while ability to handle severe short circuits, stability, robustness, and ability to operate in parallel with other equipments is discussed in more detail. The paper indicates clearly that glass-bulb rectifiers are suitable for traction service and in some respects show to advantage over other types of conversion equipment, particularly in the multiunit construction, lack of troublesome auxiliaries, high over-all efficiency, reliability, negligible maintenance costs, and flexibility.

41-101—Electric Locomotive Application: *E. W. Brandenstein* (*M'37*) *and D. R.*

Membership—

Mr. Institute Member:

For the eight-month period ending March 31, we have received 1,627 new applications for membership, compared with 1,573 for the same period of last year. This is good and we appreciate your help.

However, only 852 applications were received in this period from Enrolled Students, as compared with 883 for same period last year. We need your help in locating and bringing the advantages of membership to these young engineers. Co-operation with your Section membership committee in this matter will be appreciated.

C. C. Brill

Chairman, National Membership Committee

MacLeod (A'33). 20 cents by mail. An electric locomotive of balanced design suitable for high-speed service, either passenger or freight, is a modern development in railroad motive power. This paper presents curves which show how high horsepower at speed can supplement momentum operation to haul heavy trains over difficult profiles. The characteristics of the principal parts of electric locomotives are discussed, and the engineering fundamentals which enter into their selection are outlined. The conclusion is drawn that the electric locomotive is capable of moving more gross ton miles per train hour with fewer units than any other type of motive power.

Power Transmission and Distribution

41-94—Conductor Vibration—the Theory of Torsional Dampers; *James W. Speight. 20 cents by mail.* The paper is a theoretical treatment of the torsional damper which has been applied effectively on transmission-line conductors for the suppression of æolian vibrations. The formulas of the energy dissipation are derived for three cases: a single rigid damper, two rigid dampers at one end of a span, and a single damper with a resilient joint at the center of gravity. The results are valuable in understanding the mode of operation of the torsional damper and point to certain optimum features of design. The formulas can be used for numerical calculations, if the requisite physical constants are known.

41-97—Measurement and Control of Conductor Vibration; *Gordon B. Tebo (A'36). 20 cents by mail.* A method is outlined for determining the effectiveness of devices used for preventing vibration fatigue in transmission conductors. Measuring equipment described provides field records of conductor vibration in the quantitative form essential for such determinations. Records obtained on typical constructions are analyzed and correlated with fatigue tests and operating experience to determine the probable life of the conductor. Data are given on the performance of various devices, including a special loose-core conductor, a double-suspension clamp, armor rods, Stockbridge dampers, and a newly developed torsional damper. Of the devices tested, dampers are shown to be most effective in reducing vibration stresses.

41-95—The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario—II; *A. H. Frampton (M'28) and E. M. Wood (M'25). 20 cents by mail.* At the summer convention of the Institute in 1930 Mr. E. T. J. Brandon presented a paper under this same title, describing the design of the initial components of this system, which had then been in operation approximately one and one-half years. At that time, one and one-half circuits, having a combined length of 350 miles, were in service, transmitting approximately 150,000 horsepower to a receiving terminal station in the Toronto area of 180,000-kva capacity. At the present time, the Commission is operating a total of 1,000 miles of single-circuit 220,000-volt construction, with one receiving terminal of 420,000-kva rated capacity, and is placing into service immediately 45 miles of double-circuit construction and a second receiving terminal of 150,000-kva capacity. This paper presents a brief history of the development of the system and places on record the experience gained in 8,400 circuit-mile-years of operation of the transmission circuits. Data are presented regarding lightning outages and the behavior of the circuits under sleet and conductor vibration. These data are then used to indicate the reasons for certain revisions made in the design of new single-circuit construction carried out during 1940–41, and to indicate the factors that influenced the design of a new 45-mile double-circuit extension. The paper concludes with a discussion of the relay protection system and the improvements now being incorporated therein.

Protective Devices

41-102—Development in Lightning Protection of Stations; *E. R. Whitehead (M'39). 15 cents by mail.* Effective direct-stroke lightning protection for high-voltage high-capacity stations can be obtained by the use of the overhead ground wire, transformer-mounted arresters, and line entrance back-up gaps or protective tubes. For stations on subtransmission systems employing wood insulation throughout, overhead ground wires are usually not economical, and lightning strokes having high rates of current rise may cause either arrester or transformer failures. A reactor can be employed to compensate for the "turn-up" of the gap or tube flashover characteristic, and provide a high degree of direct-stroke protection for the transformer winding.

41-100—Field Investigations of Lightning; *C. F. Wagner (F'40), G. D. McCann (A'38), and Edward Beck (M'35). 25 cents by mail.* During the past two years lightning investigations have been carried out by the Westinghouse company by means of specially devised instruments, chief of which is the fulchronograph. The stations at which these instruments are located are of two kinds; first, those designed to measure the total current in direct strokes, and second, power system stations designed principally to measure the discharge currents in protective devices. Considerable information has been obtained regarding the multiple character and wave shape of the current in the discharges for both types of stations. These data, in conjunction with other data on the field performance of arresters, have revealed definite differences between the nature of direct strokes and the currents they produce in arresters. They also show that the nature of the system grounding affects the character of the currents discharged by arresters.

41-99—Bus Protection Independent of Current Transformer Characteristics; *G. Steeb (M'34). 15 cents by mail.* Reliable high-speed bus protection can now be provided by a method which requires neither matched current transformers nor the insulation of all equipment from ground. Standard-made, high-speed, directional and plunger-type relays of simple design provide the basic means of bus protection. A salient feature of this scheme is that false tripping, because of defects in its circuits or mistakes made by maintenance men, is very unlikely.

Standards • • •

Co-ordinating Committee 7 Establishes Subcommittee

A subcommittee of standards co-ordinating committee 7, on conduction in vacuum and low-pressure gases and vapors, has been organized under the chairmanship of Thomas Spooner, manager of the engineering laboratories and standards department of the Westinghouse Electric and Manufacturing Company. This subcommittee will carry on, within its assigned scope, the usual activities of the co-ordinating committees. More specifically, it will attempt to work out guiding standards relating to devices which depend in their operation upon conduction in vacuum and low-pressure gases and vapors, as was done for machines, transformers, etc in AIEE Standard No. 1. One of the first tasks will be to classify the various types of vacuum and gas-conductivity devices according to basic principles of operation, structural features, and utility; also, to correlate, supplement, and bring up to date existing definitions as proposed by various standardizing bodies.

Apparatus Bushings. A proposed AIEE Standard on Apparatus Bushings, No. 21, is now available in pamphlet form. This has been issued for trial use. It was developed by the joint committee on bushing standardization working under the chairmanship of R. T. Henry. These proposed standards specifically cover the following types of bushings: outdoor bushings for large apparatus; cover-type bushings for small apparatus; and indoor bushings for all types of apparatus except dry-type instrument transformers, air-blast transformers, dry-type regulators, and circuit breakers rated below 5,000 volts, and nonoiltight oil circuit breakers rated 50,000 kva or less. An appendix to the standard contains a test code and the bushing requirements as specified in the standard apply to bushings when mounted for testing in accordance with the specified arrangements as given in the code. Copies of No. 21 can be obtained without charge by addressing AIEE headquarters, 33 West 39th Street, New York, N. Y.

Abbreviations for Scientific and Engineering Terms. An American Standard for Abbreviations for Scientific and Engineering Terms, Z10.1, has just been issued. This is a revision of the American Tentative Standard published in 1932. It was developed by a subcommittee of the Sectional Committee on Letter Symbols and Abbreviations for Science and Engineering. G. A. Stetson, editor of *Mechanical Engineering* was chairman of the subcommittee. Copies of Z10.1 can be obtained at a cost of 35 cents each by addressing American Society of Mechanical Engineers, 29 West 39th Street, New York, N. Y.

Personal • • •

R. E. Doherty (A'16, F'39) president of Carnegie Institute of Technology, Pittsburgh, Pa., has been appointed chairman of the Production Planning Board, recently created as an agency of the Office of Production Management to formulate a long-range program for defense and post-emergency production. Doctor Doherty's appointment as a charter member of the board was announced in the April issue, page 182. Born January 22, 1885, at Clay City, Ill., he received the degree of bachelor of science from the University of Illinois in 1909, that of master of science from Union College in 1920, and the honorary degrees of master of arts, 1931, from Yale University, and doctor of laws, from Tufts College and the University of Pittsburgh, 1936. He was employed as a student engineer by the General Electric Company, Schenectady, N. Y., in 1909, and in 1910 became designing engineer on a-c machinery. He later became assistant to the late C. P. Steinmetz (A'90, F'12) and in 1922 was appointed consulting engineer. He organized the company's advanced course in engineering and was responsible for educational work among college graduates in General Electric employ. In 1931 he was appointed professor of electrical engineering at Yale University and in 1933 became dean of the school of engineering. He has been president of Carnegie Institute of Technology since 1936. He was elected chairman of the Engineers Council for Professional Development in 1940, having served as vice-chairman 1938–39. The recipient of the 1937 Lamme Medal of the AIEE, Doctor Doherty has been active on various Institute committees. He is also a member of the Society for Promotion of Engineering Education, Tau Beta Pi, Sigma Xi, and Eta Kappa Nu, and is the author of many technical and general articles.

T. F. Ball (M'28, F'38) formerly professor and head of the department of electrical engineering, University of South Carolina, Columbia, S. C., has been appointed professor of electrical engineering at the United States Naval Academy, Annapolis, Md. He has received a commission as lieutenant commander in the Naval Reserve. Born at Richmond, Va., April 18, 1894, he received the degrees of bachelor of science (1915) from the University of South Carolina and master of science (1919) from the University of Virginia. He was instructor in physics at the University of South Carolina 1915–16, and at the University of Virginia 1916–17, and assistant professor of physics at the latter institution 1919–22. He returned to the University of South Carolina as associate professor of electrical engineering in 1925, and has been professor and head of the department since 1928. He has also carried on active practice as a consulting engineer during this period, and in 1933 was chairman of the Water Power Investigating Committee for the State of South Carolina. He was active in the formation of the AIEE South Carolina Section in 1940 and was elected its first chairman, and has been counselor for the University of South Carolina Branch since 1928. He is also a member of the American Association for the Advancement of Science and the Society for Promotion of Engineering Education.

J. W. Barker (M'26, F'30) dean of engineering, Columbia University, New York, N. Y., has been appointed special assistant to the Undersecretary of the Navy, Washington, D. C. Dean Barker, who is currently serving the Institute as vice-president of District 3 and chairman of the technical program committee and committee on award of Institute prizes, has a distinguished record of professional service. A native (1891) of Lawrence, Mass., he received the degrees of bachelor of science (1916) and master of science (1925) from Massachusetts Institute of Technology, Cambridge, where he was associate professor of electrical engineering 1925–29. From 1916 to 1925 he served in the Coast Artillery Corps of the United States Army, for a time as officer in charge of civil affairs for the American forces in Germany. He headed the department of electrical engineering at Lehigh University, Bethlehem, Pa., 1929–30, and since 1930 has held his position at Columbia. He has been active on Institute committees and in other technical societies and was recently elected to the executive committee of the council of the American Association for the Advancement of Science (*EE, Feb. '41, p. 87*).

K. W. Waterson (A'05, F'22) has retired as vice-president in charge of personnel relations, American Telephone and Telegraph Company, New York, N. Y. Born March 9, 1876, at Chelsea, Vt., he received the degree of bachelor of science in electrical engineering at Massachusetts Institute of Technology in 1898. He entered the employ of American Bell Telephone Company, AT&T predecessor, in Boston, Mass., immediately after graduation, in 1905 was placed in charge of traffic engineering, and in 1906 in charge of both traffic and central-office engineering. Upon reorganization of the engineering department in 1909 he was made engineer of traffic, and in 1919 was placed in charge of the department of development and research, continuing to head the traffic-engineering section of the engineering department. In 1920 he was made assistant chief engineer of the department of operation and engineering, and in 1927 assistant vice-president. He has been vice-president in charge of personnel relations since 1937. He also resigns as a director of Bell Telephone Laboratories, Inc.

John Morse (A'09) formerly assistant general manager, Shawinigan Water and Power Company, Montreal, Quebec, Canada, has been appointed vice-president in charge of operation. He was born February 20, 1881, at Sjurberg, Rattvik, Sweden. After working as a draftsman for the Maxwell-Briscoe Motor Company, Tarrytown, N. Y., and for General Electric Company, Schenectady, 1906–07, he was employed by the Shawinigan company in 1907 and has been associated with the company continuously since as draftsman, superintendent of operation, general superintendent, and assistant general manager. He is chairman of the national Canadian committee of the International Conference on High-Voltage Electrical Systems (CIGRE), past president of the Canadian Electrical Association, and also a member of the Engineering Institute of Canada.

A. R. Rutter (A'35) has been appointed manager of engineering, meter division, Westinghouse Electric and Manufacturing Company, Newark, N. J. A native (1894) of Wellsburg, W. Va., he received the degree of bachelor of science in electrical engineering from the University of Pittsburgh in 1917. After working for a short time for the Duquesne Light Company, Pittsburgh, Pa., and the Pittsburgh Experiment Station of the United States Bureau of Mines, he was employed in the engineering department of the Westinghouse company at East Pittsburgh. He was made section engineer in the meter division when the division was transferred to Newark, N. J., in 1928, and a few months ago was appointed assistant manager of the engineering department of the division (*EE, April '41, p. 182*).

L. H. Hill (A'22, F'38) formerly engineer in charge of transformer division, Allis-Chalmers Manufacturing Company, Milwaukee, Wis., has been made assistant manager of the company's electrical department. After receiving the degree of electrical engineer from Cornell University in 1922, he entered the transformer engineering department of the Westinghouse Electric and Manufacturing Company, and was placed in charge of power transformer development in 1925. He became manager of the transformer division of the American Brown Boveri Company, Camden, N. J., in 1928, and continued in that position after Allis-Chalmers took over the company in 1931.

E. S. Webster (A'91, M'07) co-founder of the firm of Stone and Webster, Inc., Boston, Mass., has been elected chairman of the board. The office of vice-chairman, formerly held by Mr. Webster, has been eliminated. Mr. Webster was born August 26, 1867, at Boston, Mass., and received the degree of bachelor of science from Massachusetts Institute of Technology in the electrical-engineering course in 1888. In 1889 he formed with the late C. A. Stone (A'91, M'07) the engineering firm of Stone and Webster, which he headed jointly with Mr. Stone until the latter's recent death (*EE, April '41, p. 183*).

G. B. Shanklin (A'16, M'29) application engineer, central station department, General Electric Company, Schenectady, N. Y., has received a Charles A. Coffin award for the development of a low-voltage gas-pressure cable. This is his second Coffin award, the first having been presented in 1932 for improvements in installation of oil-filled cable. Mr. Shanklin has been with General Electric since graduating from the University of Kentucky with the degree of bachelor of mechanical engineering in 1911, and has been with the central station department since 1922.

H. J. Klumb (A'16) formerly assistant superintendent of electrical distribution, Rochester, N. Y., Gas and Electric Corporation, has been made superintendent of electrical distribution. He received the degree of bachelor of science in electrical engineering from

Mississippi Agricultural and Mechanical College in 1912, and after four years with the Westinghouse Electric and Manufacturing Company, was employed in the meter department of the Rochester Railway and Light Company, predecessor of the present company, in 1916.

W. R. LaMotte (M'36) formerly superintendent of the Essex generating station of the Public Service Electric and Gas Company, Newark, N. J., has been appointed assistant general superintendent of generation, general office, a newly created position. A graduate of Clemson College (1912), he has been associated with the company and its predecessors since 1914, except for service in the United States Navy, 1917–18, and has been superintendent of the Essex station since 1926.

J. F. Calvert (A'27, M'35) professor and chairman of the department of electrical engineering, Northwestern Technological Institute, Evanston, Ill., has been appointed a civilian employee of the United States Navy, with headquarters at Washington, D. C. **E. W. Kimbark** (A'27, M'35) assistant professor of electrical engineering, has been made acting chairman of the department for the period of Chairman Calvert's absence.

R. C. Giese (A'19, M'32) formerly district plant superintendent, American Telephone and Telegraph Company, Springfield, Ill., has been appointed division plant superintendent, division 1, long lines department, New York, N. Y. **H. H. Nance** (M'24), plant extension engineer, has been appointed engineer, long lines department, and **J. E. Dingman** (M'37) formerly division plant superintendent, division 7, becomes plant extension engineer.

H. B. McIntyre (M'38) formerly general commercial engineering assistant, New England Telephone and Telegraph Company, Boston, Mass., has been appointed general commercial toll-rate engineer. He entered the telephone business in 1922 in Manchester, N. H., becoming division commercial engineer of the southern division of the New England company in 1926, rate engineer of the southern area in 1929, and assuming his former position in 1935.

F. J. Chesterman (A'20, F'22) vice-president and general manager, western division, Bell Telephone Company of Pennsylvania, Pittsburgh, Pa., has been made vice-president in charge of operations, with headquarters at Philadelphia. He has been associated with the Bell System since 1905, going to the Pennsylvania company in 1920 as chief engineer, and being appointed vice-president and general manager of the western division in 1926.

Alexander Wilson, 3d (A'15) formerly manager, electric operations department, Philadelphia Electric Company, Philadelphia, Pa., has been appointed manager of the company's newly formed transmission and distribution department. **G. S. Van Antwerp** (A'25) formerly general superintendent of electric transmission and distribution, continues as general superintendent of the new department.

G. C. Tenney (A'35) editor, *Electrical West*, McGraw-Hill Company of California, San Francisco, recently was elected treasurer of the Northern California Electrical Bureau. **W. P. L'Hommedieu** (M'38) manager, central station sales, Pacific Coast district, Westinghouse Electric and Manufacturing Company, San Francisco, was elected a member of the executive committee of the bureau.

P. L. Giering (A'26, M'31) former chief electrical engineer, New York World's Fair, New York, N. Y., has been appointed chief electrical engineer, Caribbean Architect-Engineer, New York, N. Y. A graduate of Rensselaer Polytechnic Institute, he has practiced as consulting electrical engineer, having worked on the Detroit and Boston vehicular tunnels, and other projects.

C. F. Craig (M'27) vice-president, American Telephone and Telegraph Company, New York, N. Y., has been placed in charge of the personnel relations department of the company. He had been head of the long lines department since his election as vice-president in 1940. A biographical sketch of Mr. Craig appeared in the August 1940 issue, page 344.

H. P. Sedwick (M'32) general manager, Public Service Company of Northern Illinois, Chicago, Ill., has been elected vice-president of the company. He will continue as general manager. A biographical sketch of Mr. Sedwick appeared in the May 1940 issue, page 216.

A. A. Schuhler (A'19, M'27) formerly protection engineer in charge of government division, American District Telegraph Company, Washington, D. C., is now employed as sales manager, Schwarze Electric Company, Adrain, Mich.

G. L. Oscarson (A'24, M'30) formerly sales manager, St. Louis (Mo.) district, Electric Machinery Manufacturing Company, Minneapolis, Minn., has been appointed chief application engineer of the company, with which he has been associated since 1922.

W. E. Poor (A'15) vice-president, Hygrade-Sylvania Corporation, Salem, Mass., has been made executive vice-president in charge of all operations of the company, with headquarters at New York, N. Y. He has been with the company since 1910.

Eric O'Hara (A'36) sales engineer, Cincinnati Gas and Electric Company, Cincinnati, Ohio, has been elected president of the Technical and Scientific Societies Council of Cincinnati for the year beginning March 1, 1941.

J. R. Charlton (A'22, M'29) formerly division plant engineer, American Telephone and Telegraph Company, St. Louis, Mo., has been appointed area plant supervisor, southern area, with headquarters at Atlanta, Ga.

O. C. Schlemmer (A'30, M'39) formerly plant supervisor, Cincinnati and Suburban Telephone Company, Cincinnati, Ohio, has been transferred to the personnel relations department, American Telephone and Telegraph Company, New York, N. Y.

J. A. Powell (M'31) formerly vice-president, Utility Management Corporation, Reading, Pa., has become associated with Stone and Webster Engineering Corporation, with headquarters at Boston, Mass.

R. R. Wisner (A'23) electrical engineer, Stone and Webster Engineering Corporation, Boston, Mass., has been appointed assistant chief electrical engineer. He has been with Stone and Webster since 1912.

L. D. Canfield (A'21) formerly vice-president and general manager, Westinghouse X-Ray Company, Long Island City, N. Y., has been appointed manager of the X-ray division.

J. O. Walz (A'21) formerly section engineer, small motors division, Westinghouse Electric and Manufacturing Company, Lima, Ohio, has been made manager of the engineering department of that division.

C. E. Mason (A'34) general plant supervisor, Indiana Bell Telephone Company, Indianapolis, has also been given the duties of general plant employment supervisor for that company.

Obituary • • •

John Henry Schumacher (A'07, M'13) president, Schumacher-Mackenzie, Ltd., contracting electrical engineers, Winnipeg, Manitoba, Canada, died April 1, 1941. He was born March 6, 1880, at Dubuque, Iowa, and received the degree of electrical engineer from the University of Minnesota in 1903. From 1903 to 1907 he was employed by W. I. Gray and Company, contracting engineers, Minneapolis, Minn., as journeyman electrician and later as assistant superintendent and superintendent. In 1908 he was construction manager for the Minneapolis Electric Equipment Company, and in 1909 went with the Charles L. Pillsbury Company, consulting engineers. He went to Winnipeg in 1911 as manager and engineer of the Mitchell-Gray Electric Company. When the company was reorganized in 1913 as the Schumacher-Gray Company, Ltd., the became treasurer and manager, later becoming president of the firm, which subsequently became Schumacher-Mackenzie, Ltd. Although continuing as president, he retired from active business in 1935. He was vice-president of the Electrical Heating Company, Ltd. and the Power and Mine Supply Company. He was also a member of the Illuminating Engineering Society, Engineering Institute of Canada, Sigma Xi, and Tau Beta Pi, western Canada committeeman for the National Electrical Contractors Association, and was active in local electrical organizations in Winnipeg.

Frederick Valdemar Henshaw (A'89, M'95) financial consultant, Wood, Struthers, and Company, New York, N. Y., died March 23, 1941. He was born August 9, 1866, at Brooklyn, N. Y., and studied at Bishops College, Montreal, Quebec, Canada, where he was for a time assistant to the professor of chemistry. He was with Evans Brothers

and Mason, Ltd., chemical works, 1885–86; in 1887 was employed by the Royal Electric Company, Montreal manufacturers of Thomson-Houston machinery; and in 1888 became design engineer for the C. and C. Electric Company, Brooklyn, N. Y. He was later employed as erecting engineer by the Crocker-Wheeler Company, Ampere, N. J., and for many years was engaged in private consulting practice in New York, N. Y. Before the World War he was employed by General Electric Company and made several trips abroad to appraise properties. He was associated for a time with Bonbright and Company, utility investment firm, and in 1922 joined Wood, Struthers, and Company as consultant. He was instrumental in drafting the bill passed by the New York State Legislature in 1927 which permitted savings banks to invest in utility bonds. He was also a member of The American Society of Mechanical Engineers.

Archibald Kane MacNaughton (A'21, M'26, F'37) distribution betterment engineer, Ebasco Services, Inc., died in March 1941 at Atlanta, Ga. He was born January 21, 1894, at Calumet, Mich., and studied electrical engineering at the University of Michigan. In 1916 he was employed in the meter department of the El Paso, Tex., Railway, Light, and Power Company, the first of several companies under Stone and Webster management with which he was associated. He became secretary to the manager in 1917. In 1918 he was made general superintendent of the Ponce, Puerto Rico, Railway and Light Company, and in 1920 went to the Blackstone Valley Gas and Electric Company, Pawtucket, R. I., as electrical engineer, later becoming superintendent of distribution. He served as electrical engineer for Stone and Webster, Inc., Boston, Mass., 1926–27, and for the Narragansett Electric Company, Providence, R. I., 1927–28. From 1928 to 1932 he was planning engineer for the Georgia Power Company, Atlanta, and from 1932 to 1938 supervising engineer for the Commonwealth and Southern Corporation at Birmingham, Ala. He had been with Ebasco Services since 1938.

George W. Whittemore (A'02) retired assistant vice-president, New York, N. Y., Telephone Company, died August 22, 1940, according to information just received. He was born December 14, 1868, in Brooklyn, N. Y., and received the degree of bachelor of arts from Columbia University in 1890, later taking graduate work in electrical engineering at Columbia and a law course at the New York Law School. He entered the long lines department of the American Telephone and Telegraph Company in 1892, and in 1899 was transferred to the Bell Telephone Company of Buffalo, N. Y., as engineer, becoming general superintendent of plant in 1902. He was appointed chief engineer of the New York Telephone Company in 1910 and in 1916 became assistant chief engineer for a group of eastern companies in the Bell System, including the New York company. He had charge of preparing the New York Telephone Company's valuation of property for Federal rate hearings in 1924, and in 1927 was appointed assistant vice-president in charge of appraisals, depreciation studies, and rate case matters. He retired in 1934.

Thomas Smith Baker (A'28, M'38) radio engineer, Tropical Radio Telegraph Company, Boston, Mass., died February 27, 1941, at Washington, D. C. He was born July 24, 1896, at Sullivan, Maine, and took the Navy electrical and radio course at the University of Washington. He was an apprentice electrician in the United States Navy 1914–17, and radio electrician in the Naval Reserve 1917–19. In 1920 he became shift engineer for the Radio Corporation of America, at Bolinas, Calif., and returned to that organization in 1928 after several years on electrical construction work for Pacific Gas and Electric Company, Yosemite Portland Cement Company, and General Electric Company. In 1930 he went with Press Wireless, Inc., Chicago, Ill., and was chief engineer 1932–36. He was superintendent of radio construction, Office of the Chief Signal Officer, United States Signal Corps, Washington, D. C., 1936–37; chief engineer, communications division, Hearst Radio, Inc., New York, N. Y., 1937–39; and had since been traveling engineer for Tropical Radio Telegraph Company in Panama.

Herbert Monroe Case (A'11, F'38) consulting engineer, Long Island Lighting Company, New York, N. Y., died at Amityville, N. Y., March 31, 1941. He was born at Hartford, Conn., September 29, 1875, and received the degree of bachelor of science in electrical engineering at Massachusetts Institute of Technology in 1899. The same year he was employed by the General Electric Company, first on installations at Boston, Mass., then in the testing department at Schenectady, N. Y. He was transferred to Cincinnati, Ohio, as sales engineer about 1902. In 1905 he became consulting engineer for the General Engineering Company, Cleveland, Ohio, and two years later manager of the Connersville, Ind., Light, Heat, and Power Company. He returned to General Electric in 1910 as engineering specialist with the New York, N. Y., office. In 1912 he became vice-president and chief engineer of E. L. Phillips and Company, New York, continuing in this position until 1933, when he became associated with the affiliated Long Island Lighting Company.

John F. Mulligan (A'29, M'37) general superintendent, electric distribution construction, Consolidated Edison Company of New York, Inc., New York, N. Y., died February 6, 1941. He was born March 1, 1881, at Rock Tavern, N. Y., and studied at the College of the City of New York. He was employed by the United Electric Light and Power Company, one of the predecessors of Consolidated Edison, in 1902. In 1911 he was appointed assistant foreman, in 1918 district foreman, in 1922 general foreman, and in 1923 assistant superintendent of the cable bureau. In 1930 he became assistant superintendent of the transmission and distribution department of the United company, and in 1933 supervisor of the transmission bureau of that and the New York Edison Company. He became superintendent of transmission and distribution for New York Edison the same year, and continued in that position with Consolidated Edison until the beginning of 1941, when he became general superintendent of the electric distribution construction department.

Henry Carter Don Carlos (F'18) chief operating engineer, Hydro-Electric Power Commission of Ontario, Toronto, Ontario, Canada, died March 29, 1941. He was born in Moniteau County, Mo., November 13, 1875, and received the degree of bachelor of science in electrical engineering from the University of Missouri in 1902. From 1902 to 1905 he was electrical engineer for the Telluride Power Company, Telluride, Colo., and from 1905 to 1912 superintendent of the Eureka, Utah, Electric Company. During the latter period he was in charge of distribution and transmission for both companies. He had been chief operating engineer of the Ontario Hydro-Electric Power Commission since 1912, in charge of operation and maintenance of all generating stations, substations, and transmission lines. He was a director of the Institute 1926–30, chairman of the Toronto Section 1924–25, and past president of the Engineers Club of Toronto.

Frank Llewellyn Moser (A'25, M'31) superintendent of maintenance, Duke Power Company, Charlotte, N. C., died March 25, 1941. He was born October 7, 1882, China Grove, N. C., and attended Lenoir College. After four years in the United States Navy he was employed in 1905 in the construction and maintenance department of the Southern Power Company, a predecessor of Duke Power Company. In 1913 he became superintendent of maintenance, in charge of installation and maintenance of all electrical apparatus, and continued in that position until the time of his death.

Harry A. Ward (A'35) foreman of generator repairs, Interborough Rapid Transit Company, New York, N. Y., died recently. He was born at New York, N. Y., December 3, 1886, and educated there. From 1901 to 1903 he was employed by the Charles A. Borne Company, on motor and generator repairs, and during the next two years by the Westinghouse Electric and Manufacturing Company, on construction of a-c generators. He had been with the Interborough Rapid Transit Company since 1905, becoming assistant foreman of armature repairs in 1915, and foreman of generator repairs in 1932.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on April 17, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Hibshman, N. S., associate professor of electrical engineering, Lehigh University, Bethlehem, Pa.

Hudson, Ralph G., professor of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass.

Spracklen, Emery E., superintendent, transmission and distribution, The Empire District Electric Company, Joplin, Mo.

Wagner, Walter C., general superintendent, meter division, Philadelphia Electric Company, Philadelphia, Pa.

4 to Grade of Fellow

To Grade of Member

Birchard, W. E., electrical engineer, General Electric Company, Pittsfield, Mass.

Bodine, H. Keith, assistant chief draftsman, Philadelphia Electric Company, Philadelphia, Pa.

Curtis, Hubert C., president, The Curtis Development and Manufacturing Company, Milwaukee, Wis.

Dalgleish, R. H., chief engineer, Capital Transit Company, Washington, D. C.

Ekvall, H. N., engineer, Philadelphia Electric Company, Philadelphia, Pa.

Jones, F. S., chief engineer, Socony Vacuum Oil Company, Inc., Boston, Mass.

Langguth, P. O., assistant manager, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Lingal, H. J., engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Lovelace, C. K., chief electrician, Oklahoma Gas and Electric Company, Enid, Okla.

Manspeaker, E. D., sales engineer, General Electric Company, Jackson, Mich.

Metz, H. E., electrical engineer, Landers, Frary and Clark, New Britain, Conn.

Oliver, J. H., assistant managing engineer, General Electric Company, Philadelphia, Pa.

Reeves, H. J., consulting engineer, H. Jack Reeves, Spokane, Wash.

Rittenhouse, L. H., professor in charge of engineering, Haverford College, Haverford, Pa.

Rudrow, R. G., electrical engineer, Atlas Powder Company, Wilmington, Del.

Schmidt, W. C., transmission line engineer, Commonwealth and Southern Corporation, Jackson, Mich.

Shawver, J. W., assistant superintendent, Oklahoma Gas and Electric Company, Oklahoma City.

Swiedom, K. L., relay engineer, West Texas Utilities Company, Abilene, Tex.

Ziev, Meyer, assistant electrical engineer, United States Navy Yard, Philadelphia, Pa.

19 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before May 31, 1941, or July 31, 1941 if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Amato, J. P., Hartford Electric Light Company, Hartford, Conn.

Cramer, T. A., General Electric Company, Schenectady, N. Y.

Crosby, S. P., General Electric Company, Lynn, Mass.

Emigh, W. F., General Electric Company, Lynn, Mass.

Erskine, H. E. (Member), United States Government, Fort Devens, Mass. (re-election).

Kaufmann, R. H. (Member), General Electric Company, Schenectady, N. Y.

Klodinski, E. J., Eastman Kodak Company, Rochester, N. Y.

Lees, W. J., Eastman Kodak Company, Rochester, N. Y.

Lind, O. L., Norton Company, Worcester, Mass.

Mansur, R. L., Westinghouse Electric and Manufacturing Company, Boston, Mass.

Miller, J. G. (Member), Zone Constructing Quartermaster Army Base, Boston, Mass.

Powers, H. B., General Electric Company, Schenectady, N. Y.

Rich, T. A., General Electric Company, Schenectady, N. Y.

2. Middle Eastern

Allison, A. J., General Electric Company, Philadelphia, Pa.

Beall, R. S., III, General Electric Company, Philadelphia, Pa.

Bibbs, J. C., Jr., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Bigelow, W. B. (Member), Rural Electrification Administration, Washington, D. C.

Black, C. H., General Electric Company, Philadelphia, Pa.

Grasser, L. G., Electric Storage Battery Company, Cleveland, Ohio.

Hoskinson, J. F., B. F. Goodrich Company, Akron, Ohio.

Jarcho, H. G., War Department, Aberdeen Proving Ground, Md.

Ladenheim, E. L., United States Navy, Naval Academy, Annapolis, Md.

Loftheim, K. J., Babcock and Wilcox Company, Barberton, Ohio.

Moir, G. R., Babcock and Wilcox Company, Barberton, Ohio.

Moosmann, H. E., General Electric Company, Erie, Pa.

Simons, S., Ordnance Department, United States Army, Aberdeen Proving Ground, Md.

Stephan, R. J., Nuvo Corporation, Neville Island, Pittsburgh, Pa.

Wallace, J. M., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

3. New York City

Bode, H. W. (Member), Bell Telephone Laboratories, Incorporated, New York, N. Y.

Crosby, W. L., Consolidated Edison Company of New York, Incorporated, New York, N. Y.

Dite, W., Signal Corps Laboratory, Fort Monmouth, Red Bank, N. J.

Kimmel, J., United States Army Signal Corps, Army Base, Brooklyn, N. Y.

Kingsbury, J. W., American Telephone and Telegraph Company, New York, N. Y.

Kunz, C. (Member), M. W. Kellogg Company, New York, N. Y.

Leek, F. L., Federal Shipbuilding and Drydock Company, Kearny, N. J.

Lester, P. M., Long Island State Park Commission, Wantagh, L. I., N. Y.

Lincoln, E. S. (Fellow), consulting engineer, New York, N. Y. (re-election).

Merrell, R. J., Phelps Dodge Copper Products Corporation, Yonkers, N. Y.

Nilan, J. J., Jr., Westchester Lighting Company, Mt. Vernon, N. Y.

Nill, E. P., Consolidated Edison Company of New York, Incorporated, New York, N. Y.

Pastorinsky, H., War Department, New York Signal Corps, Procurement District, Brooklyn, N. Y.

Reiner, J. D., New York and Queens Electric Light and Power Company, Flushing, L. I., N. Y.

Romnes, H. I., American Telephone and Telegraph Company, New York, N. Y.

Sigman, G. H., New York and Queens Electric Light and Power Company, Flushing, N. Y.

Zwick, G., United States Navy Department, New York, N. Y.

4. Southern

Charles, M. C. (Member), Tennessee Valley Authority, Chattanooga, Tenn.

Fraser, J. W. (Fellow), J. W. Fraser and Company Charlotte, N. C. (re-election).

Smith, R. L., Florida Power and Light Company, Miami, Fla.

Stroud, W. D., Okonite Company, New Orleans, La.

5. Great Lakes

Bowen, G. W., Central Illinois Light Company, Peoria, Ill.

Bush, C. R. (Member), Central Illinois Light Company, Peoria, Ill.

Heiney, C. H., General Electric Company, Jackson, Mich.

Holz, G. W., Lindberg Engineering Company, Chicago, Ill.

Johnson, M. E., 819 North Marshall Street, Milwaukee, Wis.

Killin, A. M. (Member), Union Carbide Company, Sault Ste. Marie, Mich.

Mackie, F. D., Madison Gas and Electric Company, Madison, Wis.

Nottingham, F. O., Jr. (Member), Purdue University, West Lafayette, Ind.

Peasley, F. S., Stone and Webster Engineering Company, Chicago, Ill.

Schlotterback, E. M., Central Illinois Light Company, Peoria, Ill.

Teach, C. L., Central Illinois Light Company, Peoria, Ill.

7. South West

Anderson, J. B., Public Service Company of Oklahoma, Tulsa, Okla.

Arnold, E. P., Western Union Telegraph Company, Dallas, Texas.

Buell, C. E., Western Union Telegraph Company, Dallas, Texas.

Carpenter, H., Ebasco Services, Incorporated, Dallas, Texas.

Denison, J. M., Kansas Gas and Electric Company, Wichita, Kans.

Duncan, R. J., Western Union Telegraph Company, Dallas, Texas.

Grandfield, V. O., Kansas Gas and Electric Company, Wichita, Kans.

Johnson, F. K. L., Curtiss-Wright Corporation, Robertson, Missouri.

Kantenbrink, W. J. (Member), 740 South Hampton Road, Dallas, Texas.

Matson, C. E., Kansas Gas and Electric Company, Wichita, Kansas.

McBrayer, C., Signal Office, 8th Corps Area, Fort Sam Houston, Texas.

Moody, A. F., Western Union Telegraph Company, Dallas, Texas.

Moore, J. C., Western Union Telegraph Company, Dallas, Texas.

Scribner, G. R., Southwestern Bell Telephone Company, Kansas City, Mo.

8. Pacific

Baldwin, A. T., Southern California Edison Company Limited, Los Angeles, Calif.

Earl, W. S., Lockheed Aircraft Corporation, Burbank, Calif.

Grosch, J. G., 311th Signal Aviation Company, March Field, Calif.

Kelly, E. L. (Member), Bethlehem Steel Company San Francisco, Calif.

Kloski, L. A., Navy Yard, Mare Island, California.

Osteen, W. C., Southern California Edison Company, Limited, North Long Beach, Calif.

Rollins, C. A., Ferguson and Carollo, Phoenix, Arizona.

Seemann, R. E., United States Navy, Bethlehem Steel Company, Shipbuilding Office, San Francisco, Calif.

Speir, F. H., Pacific Gas and Electric Company, Emeryville, California.

Weck, W. C., Jr., Navy Yard, Mare Island, Calif.

Williams, I. A., Cutler-Hammer, Incorporated, San Francisco, Calif.

Wright, E. B., Navy Yard, Mare Island, California

9. North West

Duffy, M. D., Northwestern Electric Company, Portland, Oregon.

Gardiner, F. E., Mountain States Telephone and Telegraph Company, Butte, Montana.

Herman, C. J. (Member), Mountain States Telephone and Telegraph Company, Helena, Montana.

Hill, C. C. (Member), Mountain States Telephone and Telegraph Company, Helena, Montana.

Karns, I. H. (Member), United States Department of Interior, Billings, Montana.

Tellwright, F. D., Pacific Telephone and Telegraph Company, Portland, Oregon.

10. Canada

Cory, S. A., Small Electric Motors Limited, Leaside, Toronto.

Evans, T. O., Montreal Island Power Company, St. Vincent de Paul, Quebec.

Flannery, D. T. (Member), Hydro-Electric Power Commission of Ontario, Toronto (re-election).

Franks, N., Canadian General Electric Company, Limited, Toronto, Ont.

Hughes, T. J., Allied Brass, P. O. Box 300, Place d'armes, Montreal.

McQuarrie, A. M., Canadian General Electric Company Limited, Peterborough, Ontario.

Total, United States and Canada, 94

Elsewhere

Beard, J. R. (Fellow), Merz and McLellan, Milburn, Esher, Surrey, England.

Glasser, O. J., United States Army, Signal Company Aircraft Warning, Fort Buchanan, Puerto Rico.

Hall, R. D. (Member), Vogue Theatres, Kingswood, South Australia.

Hunter, C. D., United States Navy, Submarine Base, Coco Solo, C. Z.

Koh, N. P. (Member), Hong Kong University, Hong Kong, China.

Narayanlal, R., Government Workshop Technical Institute, Dehri, India.

Total, elsewhere, 6

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Andriessen, Rienk, 54 Division St., Schenectady, N. Y.

Bedford, P. L., 625 W. Arlington St., Chicago, Ill.

Bluethental, Herbert, Jr., 902 Concord Ave., Wilmington, Del.

Brown, Charles A., 14631 Valerio St., Van Nuys, Calif.

Clinchard, W. C., Jr., Fajardo Sugar Co., Fajardo, P. R.

Cox, Irwin W., 924 E. Wells, Milwaukee, Wis.

Di Addario, Thomas, 3110 Wisteria Ave., Baltimore, Md.

Ernestus, A. W., 137 S. 15th St., Allentown, Pa.

Freed, John H., Olson Construction Co., 410 W. 7th St., Lincoln, Nebr.

Gregory, Herbert Scott, Y. M. C. A., Schenectady, N. Y.

Kaylin, Rubin Robert, 930 Lenox Road, Brooklyn, N. Y.

Keller, Ernest Lee, 1303 E. 8th St., Anderson, Ind.

Klatte, A. J., 5505 Agatite Ave., Chicago, Ill.

Kryder, Paul A., 1527 North 52nd, Milwaukee, Wis.

Lancaster, Eugene L., Jr., 646 N. Congress, Jackson, Miss.

Martinez, Joseph D., 550 Florence Ave., Downey, Calif.

Myers, W. H., 505 West Seaside, Long Beach, Calif.

Phillips, C. Vernon, 1019 Humboldt St., Manhattan, Kans.

Radcliffe, J. H., 334 Reid St., Peterboro, Ont., Can.

19 Addresses Wanted

Recent Section Meetings

Section	Date	Speaker	Topic and Activity	Attendance
Akron	3/11/41	K. F. Sibila, U. of Akron	"Surface Hardening by Induction"; dinner and motion pictures	68
Arizona	3/22/41	Mrs. B. W. Rockwell, Lockheed Aircraft Co.	"Application of Electricity in the Airplane Industry"; organization meeting; election of officers	41
Boston	3/11/41	M. E. Strieby, A.T.&T. Co.	"Wire Line Network for Television"; dinner	113
	3/ 8/41	Harlow Shapley, Harvard Astronomical Lab.	"Comets"	126
Cent. Indiana	3/18/41	J. E. Hobson, W.E.&M. Co.	"The Application of Capacitors," illustrated	45
Cincinnati	3/10/41	Lt. Col. L. A. Codd	"Rearmament Program"	490
	3/19/41	C. F. Wagner, W.E.&M. Co. Lieut. York, Cincinnati Police Dept.	"Mechanical Analogy of Transmission Line Surges"; dinner "Safety on the Highway"	80
Cleveland	3/ 4/41	H. B. Osborn, Jr., Ohio Crankshaft Co.	"Case Hardening by High-Frequency Induction"; technical group mtg.; inspection trip through plant	76
	3/20/41	H. C. Koenig, Elec. Testing Labs. Inc.	"Uncommon Tests of Common Devices"; dinner	131
	4/ 1/41	W. I. Senger, Gisholt Machine Co.	"Dynamic Balancing Machines"; technical session meeting	87
Denver	3/28/41	W. R. Young, U. S. Bur. Reclamation	"Aspects of the Central Valley Project"	42
East Tenn.	3/17/41	C. A. Powel, W.E.&M. Co.	"Electricity in National Welfare"; dinner	55
Erie	3/18/41	T. F. Perkinson, Gen. Elec. Co.	"Some Aspects of Railroad Electrification"	12
Florida	3/21–22/41		Annual convention of Florida Engg. Society	158
Georgia	3/10/41	J. O'D. Shepherd, Southern Bell Tel. Co.	Discussion following luncheon and films	45
	3/18/41	C. A. Powel, W.E.&M. Co.	Discussion of new devices and methods in defense work	35
Houston	3/13/41	J. L. Hamilton, vice-pres., South West Dist.	Executive committee dinner	15
	3/17/41	J. O. Perrine, A.T.&T. Co.	The Artificial Creation of Speech	1,600
Iowa	3/26/41	R. L. Witzke, W.E.&M. Co.	"A Visual Demonstration of Transient Phenomena"; joint meeting with U. of Iowa Branch	135
	4/ 2/41	Lt. Col. E. D. Cameron, Jr., 7th Corps Area	"Signal Communications in the Army"; joint with Iowa State Coll. Branch	125
Kansas City	3/ 5/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Speech"; exec. com. dinner meeting	850
Los Angeles	3/11/41	N. B. Hinson, A. A. Kroneberg, H. A. Lott, Southern Calif. Edison Co. Ltd. J. Marshal, student, U. So. Calif. S. Gally, student, Calif. Inst. of Tech.	"Interconnections Between Elec. Utility Systems in Southern Calif." "Yellowstone National Park" "History of Land Occupied by City of Pasadena and CIT"	165
Louisville	3/21/41	J. R. Weaver, W.E.&M. Co.	"Industry in Defense"	24
Madison	3/ 7/41	V. K. Zworykin, RCA Laboratory	"Image Formation by Electrons"	300
	3/29/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons, Limited"	49
Mansfield	3/14/41	C. J. Phillips, Corning Glass Works	"Modern Miracles in Glass"; illustrated	52
	3/20/41	C. F. Wagner, W.E.&M. Co.	"Mechanical Analogy of Transmission-Line Surges"	76
Maryland	3/ 3/41		Inspection trip to Boys' Vocational School	52
	3/17/41	F. M. Herring, Baltimore Transit Co. O. E. Kirchner, American Airlines, Inc.	"Electric Overhead Switches for Trackless Trolleys" "Operation of Commercial Airlines"; dinner and motion pictures	132
Memphis	3/18/41	C. L. Allday, Vocational School for Nat. Def. C. W. Peury, same	"Work Being Done for Promotion of National Defense" "Value of Airplanes and Trained Personnel"	44
Michigan	3/18/41	C. F. Wagner, W.E.&M. Co.	"Traveling Waves in Transmission Systems"; dinner	200
Milwaukee	3/29/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons, Limited"	
	4/ 2/41	A. O. Hansen, U. of Wisconsin	"Atom Smasher"	85
Minnesota	3/ 3/41	A. G. Gutteridge, Melbourne, Australia W. A. Hanley, Eli Lilly Co.	"Description of Industrial Development in Australia" "National Defense From an Engineer's Viewpoint"	100
	3/27/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons, Limited"	60
	4/ 1/41	A. C. Monteith, W.E.&M.Co.	"Trends in Electrical Apparatus Development"	47
Montana	3/24/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons, Limited"	40
Muscle Shoals	3/14/41	W. E. Comb, Electro Metallurgical Co.	"Ferrosilicon"	30
	3/14/41	K. Bryn, Chas. T. Main, Inc.	"Watts Bar Steam Plant Design"	42
N. Mex.–W. Texas	3/ 6/41	R. B. Bonney, Mountain States Tel. & Tel. Co.	"Research Ramifications"; dinner	20
	4/ 1/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"; dinner	22
New Orleans	2/28/41	F. M. Clark, G.E. Co.	"Limitations for the Successful Use of Commercial Dielectrics"	53
Niagara Frontier	3/21/41	E. H. Roy, Station WBEN	"Facsimile Transmission"; dinner meeting	52
Oklahoma City	3/11/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Speech"	1,875
	3/31/41	R. W. Sorensen, pres., AIEE M. H. Cook, Western Elec. Co.	Brief talk "Manufacture of the Combined Telephone Set"	131
Philadelphia	3/11/41	W. C. Brown, G.E. Co.	"What's New in Lighting"	510
Pittsburgh	2/25/41	Lt. Com. J. P. Thew, General Motors Corp.	"The Submarine"; dinner; motion pictures; joint with elec. sec., ESWP	450
	3/11/41	J. B. Hodtum, Allis-Chalmers Mfg. Co.	"Power-Factor Testing of Transformer Insulation"; joint with elec. sec., ESWP	118
	3/25/41	E. D. Youmans, Okonite Co.	"Developments in Rubber Insulation"	136
Portland	2/27/41	P. Peterson, Control Corp.	"Demonstration and discussion of problems of remote control and telemetering; trans. and dis. com. group meeting	75
	3/17/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons, Limited"	77
	3/25/41	L. L. Smith, Pacific Tel. & Tel. Co.	"The Transmission Phases of Exchange Plant Design"; communication com. group meeting	23
Providence	1/14/41	H. C. Drake, Sperry Products, Inc.	"Flash Butt Welding of Rails"; slides and motion pictures	25
	2/ 4/41	F. W. Bush, Allis-Chalmers Mfg. Co. R. W. Sorensen; H. H. Henline	"Trends in the Design of Modern Power Transformers" Institute activities	75
	3/11/41	Capt. C. H. J. Keppler, U.S.N.	"Types and Organization of U. S. Ships"; motion pictures	75
St. Louis	3/ 6/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Speech"	2,813
San Antonio	2/25/41	C. E. Hicks, Lower Colorado River Authority	"Carrier Relaying on Lower Colo. High Line Transmission"	60
	3/14/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"	50
	3/18/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Speech"	57
San Diego	3/19/41	B. B. Gravitt, G.E. Co.	"Electrical Developments in 1940"; motion pictures	19
Schenectady	1/16/41	J. V. B. Duer, Penn. Railroad	"Electricity and Railroads" (technical discussion series)	100
	1/24/41	W. A. Hanley, president ASME	"Why National Defense?"	25
	2/13/41	H. H. Nugent, Rensselaer Poly. Inst.	"The Engineer as a Public Speaker"	115
	2/20/41	Messrs. Carnegie and Kelly, Gen. Motors Corp.	"Description of the Hydramatic Drive" (tech. discussion series)	360
Seattle	2/19/41	C. B. Ward A. O. Friend H. E. Nichols	"Pathology Treatment by Use of X Rays" "History of the Electrocardiograph" "Development of the X-Ray Tube"	90
	3/18/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons, Limited"	85
Sharon	3/11/41	E. O. Altree, G.E. Co.	"Fluorescent Lamp Lighting"; motion pictures	190
South Bend	3/20/41	B. Waldman, U. of Notre Dame	"Applications of High Voltage to Nuclear Physics"; dinner	57
Spokane	3/14/41	J. D. Booth, W.E.&M. Co.	"Power Line Carrier Communication"	41
	3/21/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons Limited"; dinner	40
Springfield	3/10/41	H. J. Holmquest, G.E. X-Ray Corp.	"Electrical Tools for the Medical Profession"	100
Syracuse	3/27/41	C. F. Wagner, W.E.&M. Co.	"Mechanical Demonstrator of Traveling Waves"; dinner	140
Toledo	3/26/41	E. G. Bailey, Babcock & Wilcox Co.	"Recent Progress in Steam Generation"; illustrated	400
Toronto	3/14/41	C. C. Rathgeb, Canadian Comstock Co.	"Important Electrical Installations Throughout the Dominion"	57
Tulsa	3/ 4/41	J. O. Perrine, American Tel. & Tel. Co.	"The Artificial Creation of Speech"	450

Recent Section Meetings (continued)

Section	Date	Speaker	Topic and Activity	Attendance
Urbana	2/26/41	Everett S. Lee, G.E. Co.	"Measurements in Industry"; joint with Univ. of Ill. Branch	100
	3/11/41	T. C. Shedd, U. of Ill.	"The Proposed Licensing Law for Engineers in Illinois"	12
Vancouver	3/19/41	R. W. Sorensen, pres., AIEE	"Engineering Horizons Limited"; dinner	47
Washington	2/11/41	M. G. Lloyd, National Bureau of Standards	"Electric Codes"	
		G. F. Daly, Int'l. Business Machines Corp.	"The Punched Card Method"	
		R. L. Palmer, Int'l. Business Machines Corp.	Demonstration of various machines	220
	2/27/41	Charles Kerr, Jr., Westinghouse E.&M.Co.	"Railroad Electrification"	78
	3/ 8/41	G. W. Spangler, Washington Terminal Co.	Conducted inspection trip	117
	3/17/41	P. Thomas, W.E.&M. Co.	"Adventures in Elasticity"	300
	3/27/41	R. G. Shaner, W.E.&M. Co.	"Illumination"	70
W. Virginia	2/14/41	J. R. Thumm, Owens-Corning Fiberglas Corp.	Discussion of electrical insulating properties of Fiberglas	26
Wichita	2/19/41	S. L. Goldsborough, Westinghouse E.&M. Co.	"Carrier Current Channels and Their Uses"; illustrated	34
	2/28/41	J. O. Perrine, American Tel. & Tel. Co.	"The Artificial Creation of Speech"	1,035
	3/24/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"	33
Worcester	3/14/41	F. Mohler, G.E. Co.	"The Amplidyne—A New Tool of Many Uses"; dinner	80

Recent Branch Meetings

Branch	Date	Speaker	Topic and Activity	Attendance
Alabama Poly. Inst.	3/10/41		Business meeting	20
Alabama, Univ. of	3/17/41	D. D. Wendel, Alabama Power Co.	"Safety in the Field and Laboratory"	25
	3/31/41		Discussion of plans for coming Student Branch convention	38
Alberta, Univ. of	1/ 9/41	E. King, student	"Remote Metering"	24
		G. Sutherland, student	"Photography"	
	1/20/41	W. Baylis, student	"Radio Beam for Flying"	20
		D. Gardner, student	"Use of Wireless at Sea"	
	2/ 4/41	H. L. Creighton, student	"Clock Motors"	21
		S. C. Phillips, student	"First Aid to Electrical Shock"	
		M. Dewis, student	"The Canmore Mine"	
	2/26/41		Motion pictures	50
	3/12/41	D. Barchyn, student	"Lighting Systems"	21
		G. Hollenbach, student	"Selsyn Motors"	
	3/31/41	J. Martin, student	"Television Scanning"	18
		G. Osberg, student	"Airport Construction"; election of officers	
Arkansas, Univ. of	3/10/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"	36
	3/12/41	F. L. Johnson, student	"Power Factor Correction"	16
		G. Scott, student	"Wave Dotter for Wave Oscilloscope"	
		H. Campbell, student	"Commutation as a Designing Problem"	
	3/19/41	Wm. Doyne, student	"Fiber Glass Insulation"; motion pictures	16
	3/26/41	F. Lewis, student	"High Efficiency Grid Modulation"	21
		J. Dragon, student	"Sodium Vapor Lamps"	
	4/ 2/41	R. A. Pittman, student	"Development and Increased Use of the Trolley Bus"	18
		H. Pristoe, student	Demonstration and talk on the theory of television transmission	
B. C., Univ. of	3/19/41	D. Beatin, student	"Photoelectric Pickup"	28
		E. Tuley, student	"Synchronous Ignition System"	
			Election of officers	
Brooklyn, Poly. Inst. (R.)	2/24/41	Capt. W. E. Appleton, U. S. Signal Corps	"Outline of Signal Corps of U. S. Army"	40
Calif., Univ. of	1/28/41	R. O. Brosemer, G.E. Co.	"General Electric Test Course"	52
	3/12/41	J. V. Lebacqz, Univ. of Calif.	"High Voltage Phenomena"; visit by Vice-Pres. H. W. Hitchcock	38
	3/14/41		Inspection trip to the Moore Drydock plant in Oakland	17
	3/27/41		Executive committee meeting	11
	4/ 2/41	D. I. Cone, Pacific Tel. & Tel. Co.	"Carrier Systems"	50
Clemson Agri. Col.	3/13/41	J. E. Woodward, student	"Cathode Vector Analysis"	26
		W. H. Wigington, student	"Train Automatic Signaling"	
	3/26/41	D. C. Sheldon	"Engineering Mathematics"	24
Colorado State Col.	3/24/41		Motion pictures	23
Colorado, Univ. of	2/ 5/41	L. M. Robertson, Public Service Co. of Colo.	"Power Systems"	30
	2/25/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Speech"	1,200
Cooper Union	11/13/40	Mr. Krecreft, N. Y. Tel. Co.	"The Science Behind the Telephone"	54
	11/27/40	Wm. Pagdin, student	"Operation of Westinghouse Elevators"	28
	12/11/40	B. Loughlin, Haseltine Service Corp.	"Phase Angle Measurements at High Frequencies"	27
	1/ 8/41	S. Bonwit, student	"Television Fundamentals"	42
	2/10/41	S. N. Baruch	"The Proposed 300,000-Volt D-C Transmission Line for the Bonneville and Coulee Dam Projects"	35
	2/28/41	S. Deutsch, student	"Repair of D-C Motors"	36
	3/20/41		Motion picture	26
	3/29/41		Inspection trip, propulsion power equipment of Ind. subway	19
Denver, Univ. of	3/ 6/41		Discussion of plans for future meetings	25
Idaho, Univ. of	3/11/41		Motion pictures and discussion of future plans	22
Ill. Inst. of Tech.	3/21/41	P. B. Juhnke, Commonwealth Edison Co.	"Operation of a Large Power System"	40
Iowa State Col.	4/ 2/41	Col. Cameron, Signal Corps, U. S. Army	Discussion of the part of the Signal Corps in army maneuvers	120
Iowa, Univ. of	3/12/41	D. J. Blacketer, student	"Use of Radio in Special Emergencies"	37
		B. Boyer, student	"Development of Television"	
		B. Blakesly, student	"How Fast Can We Fly"	
	3/26/41	R. L. Witzke, W.E.&M. Co.	"A Visual Demonstration of Transient Phenomena"	60
	4/ 2/41	E. L. Goss, student	"Ultrasonics"	34
		R. J. Fountain, student	"Niagara Falls Power"	
		H. R. Cummings, student	"Radio Advertising"	
Kansas State Col.	2/27/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Human Speech"	1,200
	3/ 6/41	John Weary, student	"The Electrical System of the Automobile"	95
		John Newacheck, student	"The St. Lawrence River Project"	
	3/24/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"	89
Kansas, Univ. of	3/ 6/41	L. L. Davis, Kansas City Pub. Serv. Co.	"Application of Electrical Energy to Transportation Problems in Kansas City"	40
Kentucky, Univ. of	3/21/41	G. Smithwick	"Ancient Customs and Modern Medicine in China"	60
	3/28/41	Paul Kintner, student	Talk	50

Recent Branch Meetings (continued)

Branch	Date	Speaker	Topic and Activity	Attendance
Lafayette Col.	3/ 5/41	P. R. Beard, student	"Electrical Control of A-C Frequency"	15
		F. T. Love, student	"Summer Work With the American Gas & Elec. Co."	
Louisiana State Univ.	3/11/41		Discussion of future plans	19
	3/18/41		Election of officers	30
Maine, Univ. of.	3/13/41	R. E. Baker, Boston & Maine Railroad	"Air Brakes"	10
Manhattan Col.	3/19/41		Organization meeting	
Marquette Univ.	2/27/41	H. Rass, student	"Rectifiers"	10
		D. Thor, student	"The Calculating Board"	
	3/27/41	C. G. Miller, Weston Instrument Co.	"Electrical Indicating Instruments"	57
Maryland, Univ. of.	3/12/41	H. Keller, student	"The Electrical Engineer in National Defense"	15
		R. Crump, student	"Power Rates"	
	4/ 2/41	G.L. Davies, Washington Inst. of Technology	"Instrument Landing of Airplanes"; election of officers	20
Michigan Col. of M.&T.	3/12/41	R. Cronshey, student	"Manufacture of Vacuum Tubes"	16
Michigan, Univ. of.	3/20/41	J. S. Gault, Univ. of Michigan	"Induction Motors—Rotor Bar Currents"; illustrated	45
Mississippi State Col.	3/11/41	Z. G. Taylor and Mr. Smithley, G. E. Co.	Talk and demonstration on the development of the lamp industry	32
Mo. School of M.&M.	3/15/41	Sargeant Wickham, Mo. State Police	"State Police Radio System"	23
	2/12/41	L. L. Crump, James R. Kearney Corp.	Various difficulties encountered in design of elec. apparatus	27
Montana State Col.	3/25/41		Election of officers	30
	4/ 1/41	J. Cummings, student	"New Transformers"	27
		A. Dalcerro, student	"Santa Fe's New Freight"	
		T. Heberly, student	"Electric Timing Devices and Corrections"	
Nebraska, Univ. of	3/ 5/41	P. E. Massie, student	"Radio in Field Artillery"; motion pictures	43
	3/19/41	H. Bishop, student	"Neon Signs"	31
	4/ 2/41	L. Haining, student	"Radio for the Weather Man"	27
Nev., Univ. of	2/27/41	K. Knoph, W.E.&M. Co.	"Fluorescent Lighting"	11
Newark Col. of Engg.	3/10/41	R. A. Dehn, student	"An Electronic Frequency Meter"	40
		V. Friberg, student	"Vacuum Tube Characteristics With Cathode Ray Oscilloscope"	
		M. Bell, student	"Phase Measurement Based on Vacuum Tube Voltmeter Operation"	
	3/24/41	C. Oriel, student	"The Ionosphere"	29
		F. Slamer, student	"Saturated Iron-core Reactors"	
		S. Kauklis, student	"The Development of Fluorescent Lighting"	
New Mex. State Col.	3/13/41	A. Westbrook, student	"Impulse Testing"	12
	3/27/41	C. Fleissner, student	"A Review of Fluorescent Lamps and Lighting"	11
		H. Harris, student	"The Petersen Coil"	
New Mex., Univ. of	3/ 6/41		Inspection trip to local power plant	16
	3/19/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"	23
	4/ 3/41		Motion pictures	16
N. Y., Col. of City of.	3/13/41		Motion pictures	50
New York Univ.	3/ 7/41		Election of Harold Eskin as secretary	22
N. C. State Col.	3/ 4/41		Discussion of fair exhibits	41
N. Dak., Univ. of.	3/13/41		Business meeting	14
	3/27/41		Business meeting	10
Northeastern Univ.	3/11/41	Wm. Lamb, student	"Manufactured Switchboards"	20
	3/18/41	L. Ellms, Ohio Brass Co.	"Manufacture of Electrical Porcelain"	53
Notre Dame, Univ. of.	3/ 4/41	H. L. Olesen, Weston Elec. Instrument Co.	"Six Types of Mechanisms Used in Weston Instruments"	35
	3/25/41	Mr. Peasely, Bendix Corp.	"What is Expected of an Engineer"	33
Ohio Northern Univ.	3/27/41		Quiz program	34
Oklahoma A.&M. Col.	3/ 3/41	J. O. Perrine, A.T.&T. Co.	"The Artificial Creation of Speech"	1,400
	3/22/41	J. L. Hamilton, vice-pres., South West Dist.	"Engineering—Past, Present, and Future"	31
Oklahoma, Univ. of.	3/12/41	J. B. Milner, student	Topics of general engineering interest	15
		L. Dorsett	"Seismograph Work"	
Pratt Inst.	3/15/41		Inspection trip to Underwriters' Labs. Inc.	7
Rensselaer Poly. Inst.	12/11/40	G. L. Johnson, Bell Tel. Labs.	"Carrier Currents' Place in Telephony"; illustrated	38
	2/18/41	J. L. Harvey, New York Power & Light Corp.	"Problems Which Occur in Power Production"	43
	3/11/41	K. P. Applegate, Hartford Power & Light Co.	"Specifications for Engineering Success"	40
R. I. State Col.	10/30/40	W. B. Hall, counselor	"General Aspects of Frequency Modulation and Television"	25
	11/20/40	G. W. Patten, G.E. Co.	"Motor Control Relays"	25
	1/15/41	R. E. Secord, Narragansett Elec. Co.	"Problems and Methods of Power Distribution"	28
	2/25/41		Business meeting	18
	3/ 4/41	H. C. Rankin, New England Power Co.	"Metering a Billion Dollars Worth of Power"	28
	3/18/41	H. A. Baines, Narragansett Elec. Co.	"The Unexpected Wants You—Prepare"	35
S. Dak. State Col.	3/14/41		Election of officers	15
So. Calif., Univ. of.	3/ 3/41	L. Wilson, student	"Power Factor Measurements by the Vacuum Tube Voltmeter"	26
		P. Belsky, student	"Flux Patterns by Commutator Investigations"	
		E. Romero, student	"Science and Engineering at the Univ. of Southern Calif."	
		R. Hedges, student	"Electrical Method for Automatic Musical Transcription"	
	3/18/41	Edwin Morris, Westinghouse E.&M. Co.	"Industrial Electronic Applications in Los Angeles"	26
Stanford Univ.	4/ 3/41	C. Kresser, W.E.&M. Co.	"Ignitron Rectifiers"	30
Syracuse Univ.	1/18/41	L. F. Polisse, student	"New York Central Railroad's Automatic Train Control"	14
	3/15/41	A. Wolfe, student	"Key West-Havana Cable"	12
	3/22/41	C. W. Perry, student	"Optimum Voltages for Airplanes"	12
		R. Reinnagel, student	"History of Engineering"	
	3/29/41	I. M. Laurien, student	"Cyclatron"	11
	4/ 5/41	D. F. Ames, student	"Electron Microscope"	12
Texas Tech. Col.	3/20/41	J. L. Hamilton, vice-pres., South West Dist.		19
Texas, Univ. of.	3/14/41	J. L. Hamilton, vice-pres., South West Dist.	"What AIEE Offers to the Electrical Engineer"	30
	3/16/41	J. C. Perrine, American Tel. & Tel. Co.	"The Artificial Creation of Speech"	276
Tufts Col.	3/27/41	E. W. Davis, Simplex Wire & Cable Co.	"What the Engineer Should Know"	30
Virginia Poly. Inst.	3/20/41		Business meeting	30
	3/28/41	Mr. Rabb, student	"Trying to Kill Micro-Organisms by the Use of High-Frequency Electricity"	32
Washington State Col.	3/13/41		Election of officers	59
	3/21/41	R. W. Sorensen, pres., AIEE	"The AIEE and Engineering in General"	55
	3/27/41		Election of officers	60
Washington Univ.	3/24/41		Discussion of final plans for Engineers' Day	21
West Virginia Univ.	3/17/41	Mr. McCarty, student	"Mines and Countermines"	38
		Mr. Reeser, student	"The Audio Noise of Transformers"	
		Mr. Alli, student	"Automatic Control of Aircraft"	
		Mr. Deegan, student	"Magnetic Pull in Relays"	
	3/24/41	Mr. Ferguson, student	"Effect of Electric Current on Man"	38
		Mr. Linn, student	"Hydrogen Cooled Synchronous Converter"	
		Mr. Rogers, student	"High Altitude Speed Test of Interceptor Plane"	
		Mr. Kelman, student	"The Evolution of Frequency Modulation"	
Wyoming, Univ. of.	4/ 1/41	S. Phillips, student	"Radio Ranges for Guiding Aircraft"	16

Of Current Interest

National Defense

Electric Power

The electric-power industry was termed a key industry in national defense by George A. Davis, vice-president, Oklahoma Gas and Electric Company, in an address at the 13th annual engineering conference of the Missouri Valley Electric Association, of which he is president. He said that the United States in its present defense effort is more dependent on adequate power supply than in perhaps any other period of its history, and for that reason the electric-power industry is vital in national defense.

"The industry is clearly conscious of its responsibility," he declared, "and is cooperating with the Federal Power Commission to determine where additional power will be needed. While there are some apparent disagreements over power needs in certain critical areas in 1942, there are two important differences between the present power-supply situation and that in 1917–18." These, as reported by *Electrical World* are:

1. In the present situation large additions to capacity are already under construction throughout the country, whereas in 1917–18 the industry postponed or curtailed construction because of rising costs.

2. Present advanced technical knowledge permits the power industry to take full advantage of interconnecting networks, a condition which was impossible in 1917–18.

ST. LAWRENCE SEAWAY PROJECT DEBATED

Proponents and opponents of the St. Lawrence River Seaway–Power Project are debating the advisability of undertaking the project at the present time. Approval of the project as a national-defense measure has been asked by President Roosevelt on the basis of an agreement coming under the Canadian American Treaty of 1909 and therefore requiring only a simple majority vote in each house of Congress.

Opponents of the project point out that should a power need develop during the national emergency in the area that could benefit from the St. Lawrence project, such need would have to be met by other means because power could not be developed in the proposed St. Lawrence plant before 1945. Therefore undertaking the project now would impose an added burden on the construction industry without contributing anything substantial to the present emergency. They point out also that no general shortage of electric power has been shown, and that furthermore modern steam plants can produce and deliver energy more economically than hydroelectric plants which must deliver their product over long distances. Also it is said that the waterway would be particularly vulnerable to enemy attack, and that therefore the construction of ocean-going ships in the Great Lakes would not be feasible.

Proponents of the project point to the advantages of low-cost water transportation from the Great Lakes region to the Atlantic, and draw a parallel between the present situation and the situation existing when the Erie Canal was built. They also emphasize the advantages of establishing a great shipbuilding industry in the landlocked and protected waters of the Great Lakes.

A lively debate is expected in both houses of Congress.

FEDERAL POWER COMMISSION CITES GAINS IN ANNUAL REPORT

"Adequate and dependable power supply to meet the requirements of expanding defense orders can only be assured through careful planning, because it takes from 18 months to 2 years to construct a steam-generating station, and frequently longer to build a hydroelectric project," says the 20th annual report of the Federal Power Commission recently issued. Such planning has been undertaken, the report adds, at the direction of the President and in cooperation with the Advisory Commission to the Council of National Defense, the National Power Policy Committee, and the publicly and privately owned utilities concerned.

Foundation of the defense power program, the report states, is the National Power Survey made by the Commission in 1935 which was continued by direction of the President in March 1938.

Since June 14, 1940 the Commission has been engaged in carrying out the instructions of the President in his letter of that date, in which he called upon the Commission (*a*) to translate national-defense orders into demands for power; (*b*) to keep check on the adequacy of the power supply to meet such demands; (*c*) to keep currently informed of the needs of the national-defense industries; (*d*) to keep records of the orders being placed with the electrical-equipment industry for additional capacity and the ability to meet such orders; (*e*) to plan, in co-operation with the utility industry, to meet every power need in the most economical manner; and (*f*) to work out plans, in co-operation with the utilities and other government agencies, for the protection of power supply against hostile acts.

Concrete examples of the results already obtained from defense work are stated in the report to be:

1. Increased generating capacity under construction due in part to Commission efforts, evidenced by comparison of the 5,500,000 kw under construction in 1940 with the 1,600,000 kw under construction in 1938; and an accelerated construction schedule that will put into operation in 1941 a considerable amount of new capacity originally planned for installation later. Most notable example of this activity is the action initiated by the Commission to increase capacity in the TVA area.

2. Standardization of the sizes, steam pressures, and voltages of steam turbine generators among the different manufacturers, which was worked out in a series of conferences with representatives of the electric utilities and the equipment companies.

3. Preparation of confidential instructions for restricted distribution to operating officials for the protection of generating plants against sabotage or other hostile acts.

4. Major assistance in the development of mobile generating stations and mobile transformer units, now being manufactured in commercial quantities, which have already proved their worth in emergency cases.

5. Investigating and reporting, in co-operation with other agencies, on the needs of electrical equipment and the requirements for priorities where such needs exceed the supply.

6. Definition of areas in the country where the power supply is adequate to meet the expanding needs of industry, to assist in the location of national-defense industries in such areas.

7. Investigation, in co-operation with the utilities, of the feasibility of a giant network of high-capacity transmission interconnections tying together the major power-market centers of the Eastern industrial areas.

8. Assistance to the Army and Navy in securing reliable power for their rapidly expanding needs at army camps, air bases, navy yards, and torpedo stations at reasonable rates.

POWER PRODUCTION BEGUN AT GRAND COULEE

Power production from two 10,000-kw generating units began March 22, 1941, from the powerhouse of the Grand Coulee project, two years ahead of schedule. These generators, which are station-service units, are pygmies compared with the 108,000-kw units, the first of which is expected to be completed in August of this year; another is expected to be completed in November, and a third early in 1942.

NEW GENERATOR AT WHEELER DAM

A fourth 32,400-kw generating unit was placed in operation at Wheeler Dam March 13, bringing the total installed capacity at this plant to 129,600 kw. The initial installation at this plant when completed in 1936 consisted of two units; a third was placed in operation in January 1941. Space has been provided for an ultimate installation of eight units.

Industrial Plant Expansion

Industrial-plant construction for defense purposes now includes 784 plants costing $2,138,000,000, according to a recent issue of *Engineering News Record*. This is regarded as a conservative figure because it includes only those the financing of which the United States or British government have had a hand, or for which permission for five-year tax amortization has been obtained.

The Office of Production Management has announced the appointment of a plant-site committee headed by Director Nelson of the division of purchases. Projects for new plants and initial suggestions for site locations are made by the Army and Navy, the legally authorized contracting agencies. In reviewing and approving additional plants and facilities the commiteee will give

special consideration to needs for expediting defense production, associated military factors, geographic decentralization of defense industries, and employment of available labor.

SOME CURRENT EXPANSION PROGRAMS

Some recently reported plant-expansion programs related either directly or indirectly to the national-defense program are as follows:

Westinghouse Electric and Manufacturing Company. A new three-story office building and expanded manufacturing facilities feature the expansion program of the Westinghouse Electric and Manufacturing Company's South Philadelphia works. The new building houses the company's 600 office and engineering personnel and is completely modern. Its features include continuous-strip fluorescent lighting throughout; air conditioning; soundproof floors and ceilings; and glass-block windows with double-pane "islands" of clear glass. The air-conditioning system includes steam-jet refrigeration and electrostatic air cleaning. In summer, the cooling load will be lessened by a two-inch deep "lake" of water on the roof which will absorb part of the heat of the summer sun and dissipate it by evaporation. The lighting system includes some 3,600 continuous-strip fluorescent fixtures, totaling more than three miles in length and consuming approximately 200 kw. Highest illumination in the structure is in the 300-foot-long engineering drafting room where an average level of 50 foot-candles is obtained; the level in general offices is from 30 to 35 foot-candles.

Steam turbines having an aggregate capacity exceeding 7,000,000 horsepower are being produced in the current program for naval vessels at this Westinghouse plant. Power-plant and industrial turbines with a total capacity of 2,400,000 horsepower also are being produced. To carry out this program, the plant is working 24 hours a day and the company is spending some $9,000,000 for new manufacturing shops, machine tools, and reorganization of manufacturing facilities. The plant extension program, begun last fall, is expected to be completed in 1941.

General Electric Company. At the Erie, Pa., plant of this company, new facilities are being set up in two buildings, one for the manufacture of turbines and one for gun mounts. Machine work on some of the lathes and boring mills needed for this program is being done partly in the General Electric plant under assignment of the Niles, Ohio, Tool Company, which is building the machines.

North American Aviation Corporation. At the Dallas, Texas, plant of this company a new $7,000,000 plane-assembly plant has been built and equipped to turn out more than 250 bombers monthly. Adoption of new construction routine enabled this plant to be completed in 130 days. The construction method used in erecting this building, which employed prefabricated cellular-steel bomb-resisting insulated structural units, has proved so satisfactory that it is being used in a second plant now being constructed at Kansas City, Kans.

Owens-Corning Fiberglas Corporation. This company has purchased the Lonsdale Company mill in Ashton, R. I., to expand the production of Fiberglas. This plant is to be adapted for the manufacture of fibrous glass that subsequently is woven into all-glass tapes and cloths. These are used for a variety of purposes, many of them urgently needed for defense.

Sprague Specialties Company. New machinery has been installed for the production of defense products in the company's second factory, acquired several years ago in North Adams, Mass.

B. F. Goodrich Company. A $300,000 manufacturing plant has been completed at Akron, Ohio, by this company for the expansion of facilities for processing products from Koroseal. The new plant will augment present production facilities for the treating of fabrics and manufacture of cements and lacquers, and will initiate production of a special film for packaging materials and for general industrial use. A substantial part of current production is said to be for national-defense needs.

National Roster of Scientific and Specialized Personnel

In about four months, America's Roster of Scientific and Specialized Personnel (*EE, Dec. '40, p. 521*) has listed and classified a total of 150,000 persons, and it is hoped that eventually a half million will be included in this index of the nation's scientific and technical skill, according to a report in the March 29, 1941, issue of *Science News Letter*.

Questionnaires have gone to persons engaged in practically all branches of technology and engineering, including the AIEE membership. Response to the questionnaires is said to have been excellent. Among the physicists, the first scientific field to be canvassed, 75 to 80 per cent of the questionnaires were put on file after a single mailing and one postal card reminder to those whose response was somewhat delayed. The classification of the personnel answering the questionnaire is accomplished by special machines by means of which punched cards are prepared, the holes punched in the cards indicating the various skills possessed by the individual. Sorting machines facilitate finding the personnel having any given training or skills.

The roster is proving particularly valuable in meeting the needs of the defense program for personnel having scientific and technical abilities.

National Defense a Leading Convention Topic

Technical and engineering societies are making the national-defense program a principal topic of discussion at current meetings and conventions. Three of the most recent conventions featuring this topic were those held by the American Society of Tool Engineers, Detroit, Mich., March 25–29; American Society of Mechanical Engineers, Philadelphia, Pa., April 22–23; and Chamber of Commerce of the United States, Washington, D. C., April 28–May 1.

Tooling up for defense formed the keynote of the Tool Engineers' convention and "education for defense" the central theme of the accompanying Machine and Tool Progress Exhibition. Attendance records were said to be broken by both the convention and the exhibition. The ASME meeting consisted primarily of a management conference on national-defense issues, with discussions relating to natural resources, labor relations, foreign trade, trans-

In the large drafting room of the new office building at the Westinghouse Electric and Manufacturing Company's South Philadelphia Works, some 300 engineers and draftsmen work under special fluorescent lighting. The average illumination level is 50 foot-candles

portation, consumer goods, supplies and prices, agriculture, insurance, Federal fiscal policies, and government regulation.

Positions to Be Filled Through Civil Service Examination

Notice of the following positions, which will be filled through civil service examinations, is published here as a service to members of the Institute. Application forms and full information as to requirements for examinations may be obtained from the secretary of the Board of United States Civil Service Examiners at any first- or second-class post office, or from the United States Civil Service Commission, Washington, D. C.

Engineers. On April 7, the United States Civil Service Commission announced a new examination for engineering positions in the Federal Government. Engineers making application for jobs, except those applying in chemistry, metallurgy, marine or naval architecture, should now apply under the modified terms of the new announcement. However, persons who have been rated eligible under the examinations announced in 1940 for mechanical, aeronautical, civil, or general engineer need not file new applications. They will be placed on the list of persons eligible for appointment as the result of the new examination. The positions pay from $2,600 to $5,600 a year. Applications will be rated as they are received at the Commission's Washington Office until June 30, 1942. Engineers qualified in the following specialized fields are particularly needed for the National Defense Program and are urged to file their applications at once: Aeronautical, agricultural (farm machinery), construction (airports and buildings), heating and ventilating, mechanical (industrial production and diesel design), ordnance, radio, safety, sanitary (especially public health), structural (building design), and welding. The duties of these positions will include design, construction, and research in the various branches of engineering. To qualify for the examination, applicants must have completed a four-year college course in engineering and have had broad and progressive engineering experience. In general, this experience should have been of a kind which required thorough knowledge of mathematics, economics, and the physical sciences. Under certain conditions additional engineering experience may be substituted for all or part of the education, and approved graduate study may be used for the experience requirement. The maximum age limit is 60 years.

Industry • • • •

Early Action Expected on Commercial Television

Approval of the modified standards presented by the National Television System Committee and announcement of the time for authorizing commercial television are expected as a result of hearings before the Federal Communications Commission March 20, 21, and 24, 1941.

The television standards as reported by W. R. G. Baker (A'19), chairman of the Committee, at the hearing contained some modifications made since they were reported to the FCC on January 27 (*EE, March '41, p. 145–7*). The number of scanning lines in the picture has been increased from 441 to 525, and the standard on synchronization broadened to allow the use of several alternative and interchangeable types of wave forms and modulation methods, until further tests determine the best method. The currently favored value of lines for color transmission was also modified, being increased from 343 to 375. Generally approved by witnesses at the hearings, the modified standards are expected to be accepted by the FCC as the official basis of the art of television.

Unless the national emergency prevents, the date at which commercial licenses will be issued is expected to be set for some time before the end of the year. General agreement was reached on proposed rules and regulations, except in the matter of the minimum number of program hours per week to be required in commercial broadcasting, for which the Commission suggested 30 hours and the commercial organizations favored from 10 to 15.

Wire and Cable Manufacturers Ask Return of Containers

Failure of industries to return empty shipping reels, spools, and cases in which wire and cable are delivered has resulted in an acute shortage of such containers which is threatening to delay delivery of national-defense orders, according to wire and cable manufacturers. New containers are not available in sufficient quantity for the need. Manufacturers are urging immediate return of all containers in order that present shipments may be expedited and time, labor, and materials required to build new containers may be conserved for defense purposes.

Power Facilities in Industry Reported by Census Bureau

A survey of power facilities in American industry, recently made public by the United States Bureau of the Census, shows a continued trend toward further electrification, with an increase in installed electric motors of 10,814,584 horsepower, or 30.8 per cent since the last similar survey made in 1929. Total horsepower used in American industry is 51,154,523.

The Census survey shows that 181,000 out of 183,277 factories now use power, in comparison with 193,969 out of 210,959 in 1929.

American factories are divided into those that have prime movers, and those that purchase power. The power-generating equipment in the first class amounted to 21,266,557 horsepower, and the plants driven by purchased energy had motor capacity for making use of 29,887,966 horsepower. Plants which produced their own energy showed a gain in power of 5.5 per cent in ten years while installed motors in those plants which buy energy increased 31.2 per cent.

The greatest gain in prime-mover installation was reported for steam turbines which increased by 3,564,826 horsepower, or 46.1 per cent. Steam-engine installation in these establishments decreased by 3,066,675 horsepower, or 31.9 per cent. Internal combustion engines increased by 568,958 horsepower or 46.1 per cent, and hydro-turbines and water wheels showed an increase of only 2.9 per cent. Factories having their own power plants reported as ordinarily idle 1,996,753 horsepower, indicating 19,269,804 horsepower actively in use, 65.6 per cent of which is used to drive electric generators. The kilowatt rating of electric generators in these establishments totaled 9,674,934, as against 7,793,875 kilowatts in 1929. Seventy per cent of these generators, as measured in kilowatt ratings, were driven by steam turbines.

The factories which purchased energy used a total of 45,040,866,703 kilowatt hours during the year, compared with 37,393,833,046 ten years ago.

RCA to Build Radio Research Laboratories

One of the largest radio research laboratories ever constructed will be built by the Radio Corporation of America at Princeton, N. J., David Sarnoff (M'23), president of RCA announced recently. The building, which will be called "RCA Laboratories", will be headquarters for all research and original development work of RCA and for its patent and licensing activities.

The purpose of the new laboratories, according to announcement, is to promote the growth of radio as an art and industry, to meet the needs of national defense, and to develop new products which may supply post-war employment.

Otto S. Schairer (M'13) now vice-president in charge of RCA's patent department, will be vice-president in charge of RCA Laboratories, which are to include the patent department. Ralph R. Beal, research director, will have charge of research and original development, and Doctor C. B. Jolliffe (M'34) is to be chief engineer.

George Westinghouse Scholarships Increased. The scholarship value of the fourth annual George Westinghouse "work-learn" scholarship has been increased by $420, the Westinghouse Electric and Manufacturing Company and the Carnegie Institute of Technology announced recently. The ten five-year scholarships, which will be awarded to high-school students on the basis of competitive examinations, personality, and character, will total $3,420 this year. The participants will obtain practical experience in Westinghouse plants during five summer vacations and two college semesters, and will complete eight semesters of college class work at Carnegie. This co-operative educational program was instituted in 1938. When in complete operation, it will include 50 functioning scholarships, with 10 scholarships expiring and being given to new men each summer.

NBC San Francisco Building Under Way. Actual construction was begun during April on the National Broadcasting Company's projected "million-dollar building" to house stations KGO and KPO in San Francisco, Calif. O. B. Hanson, vice-president and chief engineer of NBC, arrived in San Francisco April 4 to give final official sanction to plans for the building. Ground was broken November 14, 1940, and the construction is expected to occupy about ten months.

"America's Factories". "America's Factories", the 55th in a series of pamphlets published by the Public Affairs Committee under the editorship of Maxwell S. Stewart, presents a survey of factory growth during the last four decades, which shows an increase in manufacturing output of 276 per cent from 1899 to 1937. According to the pamphlet, the possibilities for expanding America's manufacturing industries for defense are very favorable, since the automobile industry which is particularly adaptable for defense requirements, and the machinery and chemical industries, also vital for defense, showed the most striking gains. Copies may be obtained at 10 cents each from the Public Affairs Committee, 30 Rockefeller Plaza, New York, N. Y.

Machine Tool Electrification. The annual machine tool electrification forum sponsored by Westinghouse Electric and Manufacturing Company was held April 14–16, 1941, at East Pittsburgh, Pa. Production and design problems created by the national defense emergency in the machine tool industry were the principal topics of discussion. An open forum was held on the last afternoon of the meetings, for discussion of subjects preselected by machine-tool delegates.

test for the finished product, dimensions, safety provisions for machinery, and work methods. These cover every important engineering field, and serve as a basis for many municipal, state, and Federal regulations. The 1941 list may be obtained free of charge from the ASA, 29 West 39th St., New York City.

Joint Activities •

Engineering Foundation Director O. E. Hovey Dies April 15

Doctor Otis Ellis Hovey, director of the Engineering Foundation since 1937, died April 15, 1941. He was born April 9, 1864 in East Hardwick, Vt., and received the degrees of bachelor of science, Dartmouth College, 1885; civil engineer, Thayer School of Civil Engineering, Dartmouth College, 1889; doctor of engineering, Dartmouth, 1927; and doctor of science, Clarkson College, 1933. After a year as instructor in engineering at Washington University, St. Louis, Mo., he became associated with the late George S. Morison, consulting bridge engineer of Chicago, with whom he worked from 1890 to 1896. In 1896 he became plant engineer of the Union Bridge Company at Athens, Pa., and in 1898 was sent to London by that company as consulting engineer on projects for building South African bridges. When the Union plant was bought by the American Bridge Company in 1900 he was made engineer of design for the latter at Pencoyd, Pa. He was transferred to New York in 1904 and became assistant chief engineer in 1907 and consulting engineer in 1931. In 1934 he went to Turkey to survey trade conditions for the company, and later in that year left the company and went into private practice. He was in charge of the engineering of a number of important projects, including emergency dams at the Panama Canal, extensive repairs on the Williamsburg Bridge, and building of the Port of New York Authority Bayonne Bridge. Dr. Hovey was the author of two books, "Movable Bridges", 1926–27, and "Steel Dams", 1935, and of various technical papers. He had been treasurer of the American Society of Civil Engineers since 1921 and an honorary member since 1937, and was also a member of The American Society of Mechanical Engineers, the American Society for Testing Materials, the American Railway Engineering Association, the American Welding Society, and the American Institute of Consulting Engineers.

Other Societies •

1941 American Standards. Announcement of publication of the list of American Standards for 1941 was made recently by the American Standards Association. More than 400 standards are listed, including definitions, technical terms, specifications for metals and other materials, methods of

Future Meetings of Other Societies

American Institute of Chemical Engineers. Semi-annual meeting, May 19–21, 1941, Chicago, Ill.

American Physical Society. 242d meeting, June 20–21, Providence, R. I.

243d meeting (Pacific Coast), June 1941, Pasadena, Calif.

American Society for Testing Materials. 44th annual meeting, June 23–27, 1941, Chicago, Ill.

American Society of Civil Engineers. Annual convention, July 23–25, 1941, San Diego, Calif.

American Society of Heating and Ventilating Engineers. Semiannual meeting, June 16–19, 1941, San Francisco, Calif.

American Society of Mechanical Engineers. Semi-annual meeting, June 16–20, 1941, Kansas City, Mo.

Edison Electric Institute. June 2–5, 1941, Buffalo, N. Y.

Institute of Radio Engineers. Summer convention, June 23–25, 1941, Detroit, Mich.

National Fire Protection Association. Annual meeting, May 12–17, 1941, Toronto, Ontario, Canada.

Society for the Promotion of Engineering Education. 49th annual meeting, June 23–27, 1941, Ann Arbor, Mich.

Society of Automotive Engineers. Summer meeting, June 1–6, 1941, White Sulphur Springs, W. Va.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Total Security—A Challenge

To the Editor:

Recently three articles in the technical press have come to my attention. One was by President Beard of the British Institution of Electrical Engineers, and appeared in the January 1941 issue of the I.E.E. *Journal*. Another was by W. L. Batt, past president of The American Society of Mechanical Engineers and appeared in the January 1941 issue of *Mechanical Engineering*. The third was by Charles E. Wilson, president of the General Electric Company, and was published in the March 1941 issue of ELECTRICAL ENGINEERING.

As an engineer, accustomed to reading these publications for technical information, I was interested and immensely impressed to note the emphasis which all these articles placed upon the morality of human relationships as a solution for present-day problems. It is also pointed out that leadership at this critical period must be in the hands of industrial executives and engineers rather than politicians.

The following are a few phrases quoted from these papers which I felt to be particularly significant. Mr. Beard says in his inaugural address: "Western civilization is nevertheless definable. It is the synthesis of three things: the Christian ethics, the scientific spirit, and the rule of law." At another point he says, "We as engineers must of necessity be called upon to play a major part in rebuilding the world, and we must place and equip ourselves for this task now."

The title alone of Mr. Batt's paper is significant: "Through A Glass, Darkly."

The title of Mr. Wilson's paper also is inspiring: "Total Security—a Challenge." In his discussion of "Moral Security is First Defense," Mr. Wilson refers to "the bonds of national unity which serve as a firm foundation for our moral security, the first fortification of our political and economic freedom." Later, in a summation of active steps to be undertaken, appears this remarkable statement:

> "With these thoughts in mind, then, the following steps represent the needs in this most critical stage—
>
> "1. Here I submit in all seriousness, as a first step: prayer, and a wholehearted practice of the Golden Rule."

The engineering professions have undoubtedly made great contributions to civilization as we know it today. However, everyone is beginning to realize that something besides technology is required to solve the problems which now face us all. It is inspiring to me that men of the caliber of those quoted all agree that the basic solutions to these problems are to be found, not in scientific publications, but in the Bible.

In so doing these men have presented a challenge to every other leader in the nation, whether he be in industry, in government, in labor, or elsewhere. It will be interesting to see who responds.

And it occurs to me that this challenge is not to leaders alone, it is to all of us—including you and me.

HARVEY P. SLEEPER (A'22, M'30)

(Operating engineer, Public Service Electric and Gas Company, Newark, N. J.)

To the Editor:

About six years ago, after the passage of the National Recovery Act, I, as president of the New York Association of Consulting Engineers, discussed with the secretaries of the American Institute of Electrical Engineers, The American Society of Mechanical Engineers, and the American Society of Civil Engineers, the possibility of persuading the PWA to make use of the existing setup in the construction industry, and also the possibility of an NRA Code for engineers. As a result of those discussions, I became the correspondent, as a member of the Code committee, for a group of some 15 local engineering societies over the United States, who exchanged views among themselves and with the Code committee in a very constructive way. Inspired by the article "Total Security—a Challenge" in the March issue of ELECTRICAL ENGINEERING, I sent the following letter to the 25 consulting engineers who formed that circle of correspondents and to the secretaries of the national engineering societies.

"Dear Sir:

"Probably you have read two articles recently published in the engineering press, but if not, may I urge you not only to do so, but to study them carefully, for in my humble judgment they represent some of the most constructive thinking that has been done in this country in a long time.

"The first appeared in the January issue of *Mechanical Engineering* and was written by W. L. Batt, president of S. K. F. Industries, past president of American Society of Mechanical Engineers, and now on Office of Production Management staff in Washington. The article, entitled 'Through A Glass Darkly', pointed out the necessity of planning now in the midst of the emergency to avoid a nosedive and crack-up when it is over.

"The second article, entitled 'Total Security—A Challenge in the March issue of ELECTRICAL ENGINEERING by Charles E. Wilson, president of the General Electric Company, proposed a definite program, requiring first an arm-in-arm accord among business, industry, labor, and government, from which certain courses of action would flow:

"First, a recovery stage.

"Second, a stabilizing program.

"Next, a backlog-building period to prepare for the slump after the war, and

"Last, the after-the-war period when with proper preparation we can pull out of the nosedive we certainly face.

"Mr. Wilson points out that the first move toward the arm-in-arm accord must come from business and industrial leaders and that the time at our disposal is short.

"The reason given for the preparation of these articles is the obvious fact that even though Britain wins, a new world will be born out of the tragedy which has overwhelmed Europe, and we will have to do business in that world, and unless we prepare realistically for that time we may be plunged into a depression far worse than the last one.

"Beyond that, and much more important in the long run, is the need so to prepare ourselves that we can help Britain persuade Europe to adopt democratic forms of government, by getting rid of dissension here and making democracy work better than any other scheme they may try.

"As Wilson points out, we are in the midst of a worldwide revolution in thought and ideas, which has been going on for 20 years and may continue for another 50 years, during which time the free-enterprise system has been and will continue to be severely tested.

"We can well believe that it is going to take a lot of faith and moral courage on the part of those leaders who undertake to break the ice to secure the arm-in-arm accord Wilson advocates. Therefore, it seems to me that we as engineers should recognize the responsibility of doing our share to help along such a move, and also to do some original thinking on our own account, as well as to take out our faith and moral courage and polish them up a bit ready for action.

"Mr. Wilson's address was given by him before the 1941 winter convention of the AIEE. It has been reprinted by the General Electric Company, which will send you a copy upon request."

JOHN G. EADIE

(Eadie, Freund, and Campbell, Consulting engineers, New York, N. Y.)

To the Editor:

As you and Mr. Wilson invited comments on his most comprehensive presentation of our national problem ("Total Security—a Challenge" by Charles E. Wilson, *EE, March, '41, p. 99–105*), permit me to observe that as citizens and officials we are very much like the leading character in Russell Conwell's "Acres of Diamonds". We have for over 150 years had a priceless gem or collection of gems and have proceeded to search Europe and Asia for panaceas entirely oblivious of our rich inheritance.

No less an authority than the Honorable William E. Gladstone termed our constitution "the most wonderful work ever struck off at a given time by the brain and purpose of man."

Its crowning jewel is the preamble which clearly states our national objectives.

Officially ratified, every loyal citizen should be dominated by its principles, for we are all committed to do our utmost to—"perfect national unity, establish justice, insure domestic tranquillity, provide for the common defense, promote the general welfare," and so on.

When, for instance, employers and employees, bankers and brokers, lawyers and clients, farmers and middlemen, and other groups seek to establish justice in their dealings with each other and with the public, then, and not till then, can they consider themselves worthy citizens of the republic whose flag they salute.

Just as Ohm's law dominates our electrical activities, so for total security the Preamble must dominate our personal and national activities, that our "government of the people, by the people shall not perish from the earth."

WM. B. TAYLOR (A'05, M'16)

(Electrical engineer, Plympton, Mass.)

To the Editor:

The article by Charles E. Wilson, in the March issue of ELECTRICAL ENGINEERING is worthy of much thought. It is also cheering because it illustrates a growing tendency to devote thought to problems of public welfare, on the part of intelligent men who have been traditionally too busy with their own affairs to "bother with politics". And such thought will show us, as Mr. Wilson implies, that the only hope of a solution for our problems lies in perceiving and expressing more of the Divine wisdom, which includes justice and love. "This also is a continuing necessity."

Mr. Wilson's thesis that there is a mass movement throughout the world toward revolution seems to be correct, but why? Why does the average man feel that he is being robbed of something which belongs to him? In this land of plenty, why is the annual income of 40 per cent of the families less than $1,000 per year? Is there a fundamental fault in our system which may account for much of our woe?

Let us see. All economists agree that three factories are necessary in production—labor, capital, and land, or natural resources.

The laborer is anyone who contributes by his own effort, mental or physical, to the general welfare. He supplies labor. Without him labor would not exist.

The capitalist is anyone who owns tools, machinery, or buildings used in production. He supplies the capital. Without him capital would not exist.

The landlord is anyone who holds title to natural resources. He supplies the natural resources with which both labor and capital must operate—or does he? Without him the natural resources would not exist—or would they?

On the contrary, the landlord, *as such*, performs no useful function at all commensurate with the large share of the product that he collects. And what he collects leaves that much less to be divided between labor and capital.

Is it conceivable that a wise and beneficent Creator designed the world as a means by which a few of his children should take away from the others a part of what those others produce, without rendering any return in goods or services? Is it not easier to believe that He designed the world for the use and benefit of mankind?

But "mankind" cannot operate my farm, nor your mine. How can this conflict be reconciled? Consider an example. My neighbor bequeathed his farm to his four sons jointly. Three of the boys had established other businesses and did not wish to change, but James wanted to run the farm. "Well," said James, "I will pay rent for the farm, and at the end of the year we will each take a quarter of the rent fund". This was satisfactory.

Applying this idea to the larger problem, we may let the community, as the repre-

sentative of "mankind", collect rent from me for the natural resources which I hold, and from you for those which you hold, leaving us both free to develop and use those resources. If this were done the community would have an income that would make taxes, as we know them at present, largely unnecessary. Furthermore, it would make possible a system of really free enterprise, free from much of the crushing burden of taxation and free from the necessity of paying tribute to the landlord before it could begin production. Henry George developed this philosophy quite fully years ago, and his reasoning has never been refuted.

May it not be that we are now being forced toward a choice between such a system of really free enterprise and some sort of totalitarian system?

This mass movement toward revolution may be a good thing or a bad thing. Hatred and short-sightedness may drive it toward anarchy and chaos. But wisdom and justice—enlightened self-interest, if you will—can lead it toward a higher civilization and a better humanity than the world has ever known.

J. B. GIBBS (M'35)

(Transformer engineering department, Westinghouse Electric and Manufacturing Company, Sharon, Pa.)

Some Characteristics and Applications of Negative-Glow Lamps

To the Editor:

The paper "Some Characteristics and Applications of Negative-Glow Lamps" by H. M. Ferree (*AIEE Trans., Jan. '41, p. 8*) does not include applications of glow tubes which deserve mention.

As Mr. Ferree mentioned, these glow lamps have the characteristic of illumination at the negative electrode, but he failed to state that the area of surface of electrode covered by the glow is, in the normal region, directly proportioned to the current. This characteristic makes the glow lamp applicable to use with an oscilloscope when the tube is viewed with a rotating mirror. The high breakdown and extinction potentials of these tubes mean that part of an impressed electric wave would be "cut off" (distorted by the oscilloscope). To avoid this difficulty it is common to excite the tube continuously with a high-frequency discharge so that only a small impressed potential is sufficient to cause the tube to glow. To make the tube satisfactory for viewing alternating currents the tube is made with two long colinear electrodes with a short spacing. The distance the electrode illuminates, measured from the electrode gap, is a measure of the magnitude of the instantaneous current. If the current is periodic the wave shape of the current may be seen by viewing the tube with the aid of a rotating mirror. Such an oscilloscope has been made.[1]

A second application of the glow tube is as a surge protector. If the field circuit of a magnet is opened suddenly a very high voltage will be induced in the windings. When a glow tube with a breakdown voltage somewhat higher than line voltage is placed across the field, the voltage across the field as the circuit is broken will not reach as high a value. The glow tube will begin to dissipate the energy in the magnetic field as soon as the voltage across the field exceeds the breakdown voltage. In tests made on a generator field it was found that (*a*) without a glow tube the voltage rose to 16 times normal and did not drop to zero until about 0.08 second, and (*b*) with a glow tube the voltage rose to 6.4 times normal and dropped to zero in less than 0.0025 second.[2]

A third application of the glow tube, familiar to all radio amateurs, is its use as a detector of a radio frequency circuit

In the list of references given by Mr. Ferree should be included the work of Oschwald and Tarrant[3] and of Reich[4] on the influence of light on the glow-tube characteristics. Reference might also be made to the use of the glow tube as a generator of saw-tooth oscillations,[5] even though this application has been almost superseded by the use of arc discharge tubes.

REFERENCES

1. NEON TUBE OSCILLOSCOPE AS A PRECISION SERVICING INSTRUMENT, T. P. Hover. *International Projectionist*, July 1937.

2. Littelfuse Laboratories, Chicago, Ill.; communication from E. V. Sundt.

3. V. A. Oschwald and A. G. Tarrant, *Proceedings* of the Physical Society, London, volume 36, 1924, page 241.

4. H. J. Reich, *Journal* of the Optical Society of America, volume 17, 1928, page 271.

5. THE OSCILLOSCOPE—A STABILIZED CATHODE RAY, F. Bedell and H. J. Reich. JOURNAL OF THE AIEE, volume 46, 1927, page 563 (see bibliography)

G. H. FETT (A'32, M'38)

(Department of electrical engineering, University of Illinois, Urbana)

Books Received

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ELECTRICAL MEASUREMENTS AND MEASURING INSTRUMENTS. By E. W. Golding. Third edition. Sir Isaac Pitman and Sons, London; Pitman Publishing Corporation, New York, 1940. 828 pages, illustrated, 9 by 5½ inches, cloth, $7.50. Originally designed to cover the knowledge required for certain British examinations, this textbook has been expanded to meet the requirements of electrical engineers in general. Covers theory and use of all types of electrical measuring instruments and methods, including the mathematical derivations for wave forms and transient phenomena. Contains reference bibliographies and examination questions with answers.

ELECTROMAGNETIC THEORY. By J. A. Stratton. McGraw-Hill Book Company, New York and London, 1941. 615 pages, diagrams, etc., 9 by 6 inches, cloth, $6.00. The author of this advanced text places primary emphasis on dynamic rather than on static field theory, postulating Maxwell's equations from the outset. A mathematical formulation of the general theory is followed by investigation of energy and stress relations. The properties of static fields are then discussed, and the rest of the book is devoted to the propagation of plane, cylindrical and spherical waves, the theory of radiation, and boundary-value problems. Illustrative problems.

EXPLORATION GEOPHYSICS. By J. J. Jakosky. Times-Mirror Press, Los Angeles, Calif., 1940. 786 pages, illustrated, 9 by 6 inches, cloth, $8.00. Aims to describe the fundamental theories, equipment, and field techniques of the recognized exploratory geophysical methods, and to illustrate their application to problems of economic geology. An early chapter presents the geologic and economic background, and succeeding chapters deal respectively with magnetic, gravitational, electrical, seismic, geochemical, and geothermal methods. Drill-hole investigations and oil-well production problems are also considered. Literature references in text, and patent bibliography appended to each chapter.

GEOPHYSICAL EXPLORATION. By C. A. Heiland. Prentice-Hall, New York, 1940. 1,013 pages, illustrated, 9½ by 6 inches, cloth, $10.00. Intended as a comprehensive survey of the entire field of geophysical exploration. The elementary first part describes working principles and geological applications for those not directly concerned with field or laboratory operations. The second and major part discusses the subject from an engineering viewpoint, presenting theory, field technique, laboratory procedure and geological interpretations for gravitational, magnetic, seismic, and electrical methods. Consideration is also given to minor methods and to geophysical well testing.

HISTORY OF GEOMETRICAL METHODS. By J. L. Coolidge. Clarendon Press, Oxford, England; Oxford University Press, New York, 1940. 451 pages, diagrams, 10 by 6 inches, cloth, $10.00. The methods that men have invented throughout the centuries to deal with geometrical questions are considered under three main headings: synthetic geometry, the earliest type which considers figures directly; algebraic geometry, including co-ordinate systems; and differential geometry. The work of the important pioneers in each field has been emphasized. Bibliography.

HOUSING FOR DEFENSE, by M. L. Colean. Twentieth Century Fund, 330 West 42nd Street, New York, 1940. 198 pages, diagrams, 9½ by 6 inches, paper, $1.50. The problems and experience with regard to housing during the World War are described, with attention to the resulting government policies. The present situation is compared with that of 1917–18. The relation between housing and the location of defense activities is emphasized, and community problems are discussed. The final chapters deal with the construction and financing of new housing, the relative parts to be played by private and governmental agencies, and the recommendations of the housing committee.

LOCOMOTIVES ON PARADE. By B. Hungerford. Thomas Y. Crowell Company, New York, 1940. 236 pages, illustrated, 9 by 6½ inches, cloth, $2.50. The history of the steam locomotive told in layman's language, describing the successive types that evolved, including famous individual representatives and the men who made them.

THE METER AT WORK. By J. F. Rider. John F. Rider Publisher, New York, 1940. 152 pages, illustrated, 9 by 5 inches, cloth, $1.25. This practical book for servicemen and others describes how each type of meter works, how each is used in the field, how to increase efficiency, and how to select new meters. In an unusual method of book construction, the illustrations are placed above and separate from the text for convenient reference.

MODERN AIR CONDITIONING, HEATING, AND VENTILATING. By W. H. Carrier, R. E. Cherne, and W. A. Grant. Pitman Publishing Corporation, New York and Chicago, 1940. 547 pages, illustrated, 9½ by 6 inches, cloth, $4.50. The whole field of interior conditioning is covered in this manual, which is designed to apply existing theory to actual practice in the industry. Basic theories are explained, but emphasis is placed on the engineering principles and design of equipment. Comfort and economic factors are also considered. Practical examples are presented, and tables and charts collected in an appendix.

NATIONAL ELECTRICAL CODE HANDBOOK. By A. L. Abbott. Fifth edition. McGraw-Hill Book Company, New York and London, 1940. 595 pages, illustrated, 7½ by 4½ inches, leather, $3.00. Discusses the provisions of the National Electrical Code and their practical application. These provisions are grouped in six major divisions: definitions of terms; approved types of wiring; installation of materials and apparatus; general requirements applying to all wiring systems; special cases; and construction of materials. The present edition is based on the 1940 Code.

PHYSICS OF THE AIR. By W. J. Humphreys. Third edition. McGraw-Hill Book Company, New York, 1940. 676 pages, illustrated, 9½ by 6 inches, cloth, $6.00. Provides an account of the facts and theories relating to the mechanics and thermodynamics of the atmosphere, to atmospheric electricity, acoustics, and optics, and to the factors that control climate. Revised to include recent information.

POWER IN TRANSITION. By E. R. Abrams. Charles Scribner's Sons, New York, 1940. 318 pages, maps, tables, 8½ by 5½ inches, cloth, $3.00. Describes briefly the development of the electric utilities up to the peak of private operation; then considers the growing tendency toward public control. Some 60 major power projects are analyzed, with their history through Congress engineering problems and the resources, requirements, and expectations of the several regions to be served. Probable effects of these developments of the national power policy are briefly pointed out. Chapter bibliographies.

Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the June 1941 "Supplement to Electrical Engineering—Transactions Section"

Power Supply for Resistance-Welding Machines—III

Factory Wiring for Resistance Welders

AIEE COMMITTEE ON ELECTRIC WELDING

Subcommittee on Power Supply for Welding Operations*

Purpose of Report

AN adequate power supply is one of the requisites of present-day, high-production resistance welding. A major part of the power supply system of any industrial plant lies within the plant itself and consists of the plant wiring and transformer substations. It is the purpose of this report to show how to properly lay out such a plant distribution system for serving welders. Much of the fundamental data included in the tables and charts is not new but is included in order that the layout engineer will have complete information available in one compact report and will not have to refer to various articles and handbooks, copies of which may not be readily available.

General Considerations

The first report of this series, "Guide to Good Electrical Performance of Resistance Welding Machines," pointed out the need for keeping welder kilovolt-ampere inputs as low as possible for given welding current outputs, and the next step consists of providing adequate supply facilities for handling these inputs. Because of the high currents involved, transformers should be located as close to the welders as possible, keeping the secondary bus and feeder runs short. In many cases it will be found advantageous to use transformers containing a liquid that will not burn rather than oil in order that they can be located adjacent to the welding machines rather than at some relatively remote outdoor or vault location. With the load power factor generally falling between 20 and 40 per cent, it is essential that the reactance of the power supply system be kept at a minimum. Generous copper cross section in welding feeders is usually less important than proper spacing and arrangement of the conductors for minimum reactance.

The first question to be answered is: "For what voltage drop shall the supply system be designed?" No specific answer can be given which will apply to all cases and, as pointed out in the preceding report, satisfactory results may be obtained with 15 per cent regulation in one case and 5 per cent may be too much in another. However, in general with the usual class of production resistance welding involving low and medium carbon steels, satisfactory welding will result if the voltage drop to a point on the supply system common to two or more machines does not exceed ten per cent for the largest machine of the group. This statement is based on the assumption that there are relatively few large machines in the group being served (say, not over five or ten machines) and that, while two of them may occasionally operate at the same time, the chances of three or more operating together is extremely remote. Thus, if the machines are adjusted for perfect welding with a ten per cent voltage drop in their supply circuit, the welds will still be good when two machines operate together causing nearly 20 per cent drop. If three or more happen to hit together, poor welds or rejects may result. Care should be exercised in adjusting machines, with the setting made under highest voltage and maximum current conditions, just short of burning the weld so that under minimum voltage conditions a good weld will still result.

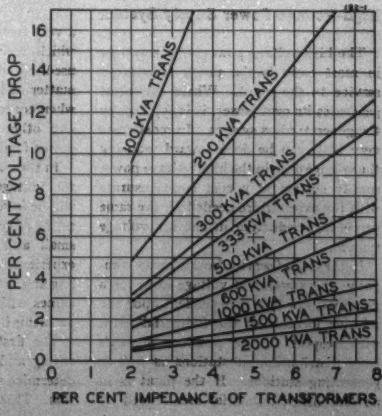

Figure 1. Welding supply—transformer regulation

Per cent voltage drop per 1,000 amperes of 30 per cent power factor, single-phase welding current

1. For 480-volt, single-phase transformer bank, use chart values of per cent voltage drop
2. For 480-volt, three-phase transformer bank, multiply per cent voltage drop by 2
3. For 240-volt, single-phase transformer bank, multiply per cent voltage drop by 1/2
4. For 240-volt, three-phase transformer bank, use chart values of per cent voltage drop

Paper 41-82, recommended by the AIEE committee on electric welding, and presented at the AIEE North Eastern District meeting, Rochester, N. Y., April, 30–May 2, 1941. Manuscript submitted November 12, 1940; made available for preprinting March 1, 1941.

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1. For all numbered references, see list at end of paper.

Experience indicates that this general rule of ten per cent drop for the largest machine will result in a good workable installation in most cases although it should be realized there will be exceptions. The procedure outlined in the following sections will follow the ten-per-cent rule with some indication as to how to determine those installations which will require special consideration as exceptions to the general rule.

Where even less than ten per cent regulation can be provided at about equal cost, such as obtained by close spacing of feeders, this obviously should be done. The ten-per-cent figure is set only as an approximate allowable upper limit and any improvement below this value is all to the good and makes for that much better welding conditions.

Interlocking can be resorted to under some conditions to insure not more than one or two machines operating at the same time. This is an inexpensive practice where only a few large machines are involved and in most cases production speed is not materially reduced.

While the current-carrying capacity of the supply feeders and transformers must receive consideration, if provision is made to keep the voltage drop within the necessary limits, there usually will be sufficient attendant thermal or carrying capacity.

Voltage Drop

For convenience, the supply system can be broken up into three parts:

1. High-voltage power supply system (2,400 volts or higher)
2. Step-down transformer bank
3. Low-voltage bus or feeder (240 or 480 volts)

High-Voltage Power Supply System

The high-voltage power supply system in most cases is the power company's service to the plant. Where the plant generates its own power, it is typified by the generator bus system. In most cases very little can be done toward reducing the voltage drop in the high-voltage power supply system at a cost commensurate with the expenditure needed for the same percentage reduction in the low-voltage system.

In the case of service from a power company, the amount of voltage drop for a given welding load is dependent upon the relative location of the industrial plant with respect to the power company's large distribution substations as well as generating stations. If the plant is in an established industrial area served by large substations and not too far from large generating stations, the voltage drop in the high-voltage system will be a negligible factor. However, if the plant has been located in a rural or small-town area far removed from the power company's main generating stations, as is becoming more common under the present-day trend toward decentralization of industry in the search for low manufacturing costs and reduced taxes, the high-voltage system regulation may loom up as a very troublesome factor. Any plant in which resistance welding is extensively used should carefully investigate this matter of high-voltage system regulation when contemplating moving the plant to any other location with less adequate power facilities for welding.

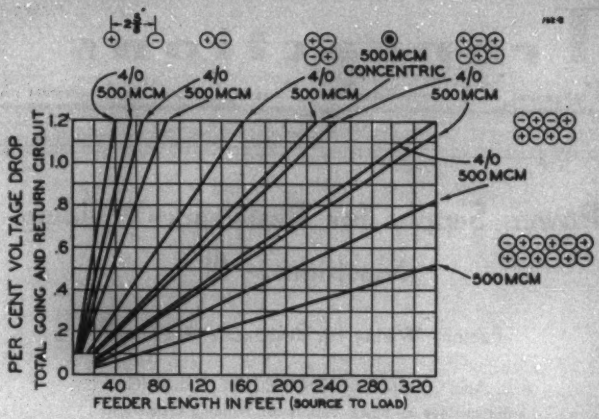

Figure 2. Welding supply—wire feeder regulation

Per cent voltage drop per 1,000 amperes of 30 per cent power factor, single-phase welding current

1. For 480-volt feeder, use chart values of per cent voltage drop
2. For 240-volt feeder, multiply per cent voltage drop by 2

In the case of private power generation, the voltage drop at the generator bus will be inversely proportional to the total rating of generators feeding the bus. The small and moderately sized plant will experience considerable difficulty in handling any but the smaller-sized welding machines without encountering lamp flicker problems in their plant and office lighting.

The first step in designing the plant wiring and bus layout for welding is to determine the high-voltage system regulation. This can be obtained from the local power company by giving them the maximum kilovolt-amperes and power factor that the largest machine will draw from the power system. Subtract the figure obtained from the total allowable ten per cent and the remainder is that which can be allowed in the step-down bank and secondary or low-voltage bus system. For instance, assume the largest welder is rated 300 kva and will deliver a maximum welding current of 100,000 amperes with a high secondary open circuit voltage of 8 volts. The approximate maximum kilovolt-ampere input (neglecting exciting current) is $(100{,}000 \times 8)/1{,}000 = 800$ kva. From the power company representative it is learned that 800 kva at an estimated 30 per cent power factor will cause four per cent drop in the power company service to the transformer bank at the customer. This subtracted from ten per cent leaves six per cent which can be used up in the step-down transformers and low-voltage bus system.

Step-Down Transformer Bank

On the assumption that the remaining allowable six per cent drop can be divided about equally between the step-down transformer bank and low-voltage bus system, it is necessary to select the proper size transformer which will limit the drop to about three per cent.

Welders can either be served from a single-phase transformer bank or a three-phase bank, and where the welding load is large enough to justify a separate transformer bank for welding load only, it will be found advantageous and more economical of capacity to use a single-phase system. The load is single phase and it will remain single phase no matter

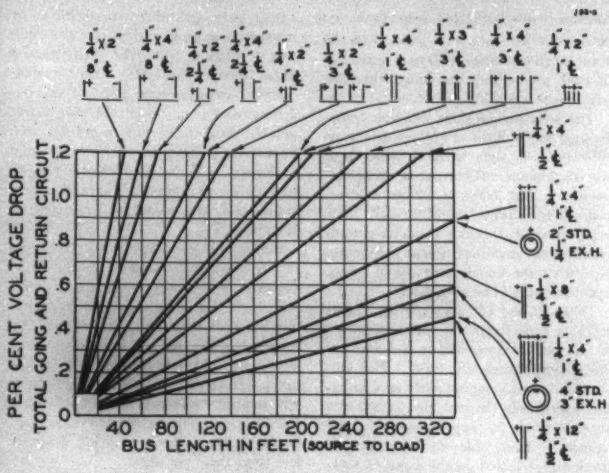

Figure 3. Welding supply—bus regulation

Per cent voltage drop per 1,000 amperes of 30 per cent power factor, single-phase welding current

1. For 480-volt bus, use chart values of per cent voltage drop
2. For 240-volt bus, multiply per cent voltage drop by 2

how the transformers ahead of it are connected. Sometimes it is desirable to spread the individual single-phase loads over the three-phase wires for more economical utilization of the supply lines, but unless there are large numbers of machines connected, the necessity for balancing the load is not important. When there are many machines, they are usually scattered around in different parts of the plant so that several step-down banks become necessary at different locations. In this case individual single-phase banks can be connected to separate phases and thus bring about some semblance of balance on the supply wires.

A given kva of single-phase load fed from a three-phase transformer bank will cause just twice as much transformer voltage drop as the same kva load fed from the same capacity in transformers connected as a single-phase bank. It is thus obvious that, where the transformer voltage drop must be kept at a minimum, it is highly desirable and more economical to use single-phase, step-down banks of transformers.

In case the welding load is relatively small in comparison with the motor and other power load of the plant, it can readily be served from the same three-phase bank serving the power load. Individual plant and service conditions thus dictate whether single-phase or three-phase banks are the logical selection. Irrespective of whether the welding load is served from single-phase transformers or from three-phase transformers in combination with the motor and power load, the lighting load should usually be handled separately in order to prevent flicker difficulties.

Figure 1 shows per cent voltage drop per 1,000 amperes of 30 per cent power factor welding current through transformer banks of different sizes and impedance. Plant practice may determine the size and impedance of individual transformers and the number of units to connect in parallel can be determined from the chart. For instance, assume that 300-kva, $3^1/_2$-per-cent-impedance transformers are used by this particular plant in its step-down banks. A load of 800 kva represents 1,670 amperes at 480 volts. From figure 1: 1,670 amperes through a 300-kva, $3^1/_2$-per-cent-impedance transformer causes 1.67 times 5.6 per cent = 9.4 per cent = voltage drop. Therefore, three transformers in parallel would have to be used to stay within the predetermined limit of three per cent drop. In some cases a special low-impedance transformer may be economically justified. For example, if a two-per-cent-impedance transformer is purchased, the nearest size transformer would be 500 kva which would allow 3.2 per cent drop. This might be cheaper than the three 300-kva transformers but would have the definite disadvantage of not being usable interchangeably at other plant locations. If a plant has sufficient welding load, it sometimes pays to standardize on special low-impedance transformers for welding only and not attempt to make them interchangeable with transformers used in power and lighting banks.

Low-Voltage Bus or Feeder

There is now only three per cent remaining out of the original allotted ten per cent drop. It is found that the bus or feeder must be 300 feet in length to reach the two machines located farthest from the transformer bank.

Figures 2 and 3 show the per cent voltage drop per 1,000 amperes of 30 per cent power factor welding current for different types and sizes of bus and wire construction. Figure 2 is for various wire arrangements and figure 3 for different bus arrangements. Some plant engineers prefer one class of construction and some the other. The bus can be made up on the job or it can be purchased, prefabricated in unit lengths either with or without enclosures.

Usually if the welders are in a fairly compact group but at some appreciable distance from the transformer bank, some arrangement of wire feeder works out to advantage. However, where the machines are scattered and frequent taps must be made to the supply wires or bus, a bus system is perhaps more advantageous in that frequent connections to it are readily made.

From the charts it is found that two 500,000-circ-mil wires per leg in conduit would handle 800 kva with 2.6 per cent drop at the 300-foot distance. (800 kva = 1,670 amperes. From the chart the drop for 150 feet = 0.78 per cent; for 300 feet and 1,670 amperes the voltage drop equals 0.78 per cent times 2 times 1.67 = 2.6 per cent.) For the bus construction a bus consisting of two $^1/_4$-inch by 4-inch copper bars on one-inch

Table I. Equivalent Continuous Loading of Typical Welding Machine Installations

Types of Welding	Equivalent Continuous Load Expressed in Per Cent of Sum of Name-Plate Ratings
Spot, projection, flash	5 to 10 (most installations) 10 to 20 (very few installations)
Hydromatic, butt	10 to 20
Seam	25 to 70

centers would be suitable from a voltage-drop standpoint.

It is possible that either of these selections may have sufficient current-carrying capacity for handling the equivalent steady or thermal load of the group of welders. However, if it is found that more carrying capacity is needed, other configurations are shown with equal or better voltage-drop characteristics.

Equivalent Continuous Thermal Loading

There are several ways in which the equivalent continuous thermal loading of a group of welders can be determined. It might be reasoned that the quickest and simplest method would be to add the name-plate kilovolt-ampere ratings of the individual welding transformers, and then apply a suitable diversity factor for group operation. The welding transformers are rated on a 50-per-cent duty-cycle basis and, consequently, if all of the machines are operated continuously right up to the thermal capacity of their transformers, the equivalent continuous thermal loading would be $\sqrt{0.50}$ or 70.7 per cent of the sum of the name-plate ratings. Thus, if there were ten 300-kva welders, the supply system on this basis should have a carrying capacity of 70.7 per cent of 3,000 kva, or 2,100 kva less the diversity factor correction.

In actual practice, however, most machines, except perhaps some seam welders, operate well below their maximum thermal capacity, because the size of transformer in the machine is dictated by the required welding current output rather than by thermal considerations.

Tests of many installations show that the values given in table I are more clearly representative of actual field conditions. Thus, if the machines are predominately spot, projection, or flash welders, a supply system with a rating of 15 per cent of the sum of the name-plate ratings of the machines would, in most cases, be adequate. Thus, taking the ten 300-kva welders, the supply system should be good for about 15 per cent of 3,000 kva, or 450 kva.

A second check should be made based upon the actual kilovolt-ampere loads of the welders and their operating duty cycles. Assume that each of the ten 300-kva machines was on a production schedule of 100 welds per hour with maximum loads of 800 kva for 10 cycles per weld. The corresponding duty cycle of each machine is: $(10\times100)/(60\times60\times60)=0.46$ per cent. The equivalent continuous load corresponding with 800 kva at 0.46 per cent duty cycle is: $\sqrt{0.0046\times800}$ kva $=54$ kva. For the total of ten machines, if all were operating at peak production, the equivalent kilovolt-amperes would be $10\times54=540$ kva.

The selection of three 300-kva transformers on the basis of voltage-drop considerations is thus perfectly safe from the standpoint of current-carrying capacity. The 500-kva, 2-per-cent-impedance transformer might be just a little small from a thermal capacity standpoint for ten machines in peak production but, with the usual diversity of group operation, should be adequate.

Tables II and III show the equivalent carrying capacity in continuous amperes of the various types of bus and wire arrangements commonly used. The ampere load corresponding with an equivalent continuous thermal load of 500 kva at 480 volts is approximately 1,000 amperes. Thus, the wire construction previously selected on the basis of voltage drop is not large enough from the standpoint of current-carrying capacity. A wire grouping consisting of four 500,000-circ-mil wires per leg (item 11, table II) is rated about 1,000 amperes and should be adequate for the job. This wire arrangement will have only 1.2 per cent voltage drop for an 800-kva load swing, thus being well within the three per cent allowed.

It should be emphasized here that the current-carrying capacities given in table II for six or more total wires in a trough or raceway enclosure are estimated values only and while considered to be reasonable approximations, they are subject to change whenever verifying test data become available. The current-carrying capacities for most of the bus arrangements in table III are extrapolated from test data of similar configurations both in the open and in metal enclosures and should, consequently, be reasonably accurate although here again, actual test data would be welcomed by the industry.

Similarly, table III shows several types of bus construction well within the three-per-cent voltage-drop allowance which will have adequate carrying capacity. The original selection of one $^1/_4$-inch by 4-inch bar per leg on one-inch centers would be adequate if mounted in the open. However, most bus installations will require enclosures and on this basis the selection would be between the heavier current-carrying busses having drops of less than three per cent.

Chance of Simultaneous Welds

Designing for a total of ten per cent voltage drop for the operation of the largest machine produces satisfactory welding conditions only when three or more machines do not happen to operate at the same instant. Based upon the general law of averages, the expectancy of simultaneous welds can be readily calculated. For the sake of simplicity, it is assumed that even if only a single

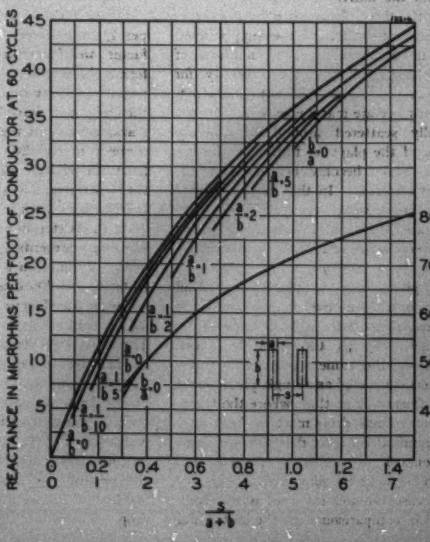

Figure 4. Reactance of trough conductors at 60 cycles

Table II. Welding Supply—Wire Feeder Data. Calculated Data Per 100 Feet of Distance From Source to Load (200 Feet of Circuit)

Item	Wires Per Leg	Spacing (See Figure 2)	Size	Area Square Inches	Approximate Current-Carrying Capacity Copper 60 Deg C Ambient 30 Deg C (Amperes)	Weight (Pounds)	D-C Resistance 25 Deg C (Ohms)	Reactance (Ohms)	Voltage Drop Per 1,000 Amperes 30 Per Cent Power Factor: Volts	Per Cent at 480 Volts
1	1	2½-inch centers	4/0	0.166	225[1]	131	0.01	0.012	14.3	2.98
2	1	2½-inch centers	500,000 circ-mil	0.393	400[1]	308	0.0043	0.0098	10.7	2.22
3	1	Wires laced together	4/0	0.166	210[2]	131	0.01	0.0059	8.72	1.82
4	1	Ditto	500,000 circ-mil	0.393	350[2]	308	0.0043	0.0056	6.63	1.38
5	2	Ditto	4/0	0.332	400[3]	261	0.0051	0.0022	3.63	0.76
6	1	Concentric cable	500,000 circ-mil	0.393	300[4]	308	0.0043	0.0013	2.53	0.53
7	2	Wires laced together	500,000 circ-mil	0.786	650[3]	616	0.0022	0.002	2.54	0.53
8	3	Ditto	4/0	0.498	500[3]	392	0.0034	0.0014	2.36	0.49
9	4	Ditto	4/0	0.664	600[3]	522	0.0026	0.001	1.72	0.36
10	3	Ditto	500,000 circ-mil	1.18	850[3]	925	0.0014	0.0013	1.63	0.34
11	4	Ditto	500,000 circ-mil	1.58	1,000[3]	1,230	0.0011	0.00089	1.17	0.24
12	6	Ditto	500,000 circ-mil	2.36	1,300[3]	1,850	0.00072	0.0008	0.79	0.17

Notes: 1. Code limit.
2. In conduit, wires laced together.
3. In trough, wires laced together (estimated values—no test data known).
4. Reactance is slightly higher when wire is in magnetic trough or conduit.
5. In conduit (estimated value—no test data known).

cycle of one weld overlaps another, this would constitute a simultaneous weld. Obviously, except for very short-time welds (two to three cycles), a single cycle overlap should not prove serious and this assumption thus introduces a considerable factor of safety.

T = total time per weld per machine, including "off" and loading time as well as actual weld time
t = actual weld time per machine
E = number of machines
$\frac{T}{tE} \times \frac{T}{t(E-1)}$ = interval in terms of number of welds between operations in which *two* machines make a weld at the same time including any slight overlapping of actual welding time
$\frac{T}{tE} \times \frac{T}{t(E-1)} \times \frac{T}{t(E-2)}$ = interval in terms of number of welds between operations in which *three* machines make a weld at the same time including any slight overlapping of welding time

In usual production welding if rejects due to simultaneous welds do not occur oftener than once per hour, which would be one weld out of every 5,000 or 10,000, conditions would probably be considered highly satisfactory. Table IV shows various combinations of machines, welding time, hourly production, and corresponding interval of time between expected simultaneous welds. For instance, 20 machines with three-cycle welding can produce 200 welds per hour per machine with an expectancy of three simultaneous welds and three rejects every 1.7 hours. With the production stepped up to 300 welds per hour per machine, the resultant expected interference might be such that it would be desirable to either split the machines into two groups or design for a five per cent instead of ten per cent voltage drop in the supply system.

The last column shows total time divided by the actual weld time of all large machines on the bus. As long as this value is greater than 10 or 20, satisfactory welding conditions should generally result on a supply system with ten per cent voltage drop, as the chances of three simultaneous welds occurring oftener than once per hour is rather remote. (For exceptions see last paragraph.) It should be remembered that these considerations apply only to the large machines. Innumerable small machines can be served from the same transformer bank and bus system along with the five or ten large machines, upon which the distribution system design is based, without any further consideration except that of thermal carrying capacity of the system.

It might not be amiss in this connection to point out another frequently encountered cause of poor welding in addition to that of excessive voltage regulation. There is a tendency on the part of many users of welding equipment to increase the welding speeds far beyond the capacity of the equipment to make good welds. As a result, a certain percentage of such welds are inferior. The designer then specifies a greater number of welds in an attempt to assure himself of a sufficient number of good welds to produce a satisfactory joint. The production department must then make these welds at an even faster rate of speed to maintain costs, resulting in an even greater number of inferior welds.

This vicious circle of events can be eliminated by insistence upon good welding throughout, resulting in fewer welds per joint, which in turn permits welding speeds commensurate with good welding. This results in better voltage regulation by reducing the chances of simultaneous or interfering welds on any given feeder line.

There may be some classes of welding where every weld must be perfect and there must be no chance of even a few undetected poor welds passing inspection. In these cases it may be desirable to design for closer regulation. However, even under these conditions, the extra investment needed for reduced regulation should be balanced against the cost of necessary recorders and indicators for detecting welds made under improper conditions of voltage, current, and time.

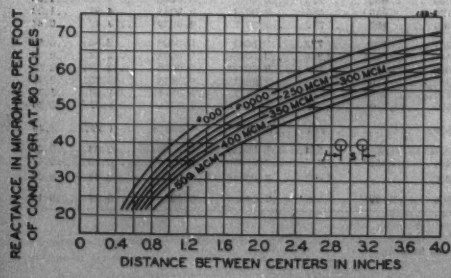

Figure 5. Reactance of standard strand cables at 60 cycles

It might be more economical to invest in the recorders and indicators than in excessive feeder and transformer capacity which would only be needed once or twice a day when three or more machines might happen to hit together.

Example. Ten 300-kva machines, each machine producing 100 welds per hour of 10 cycles duration each:

$$T=\frac{60\times60\times60}{100}=2{,}160 \text{ cycles}$$

$t=10$ cycles

$E=10$ machines

$$\frac{T}{tE}\times\frac{T}{t(E-1)}=\frac{2{,}160}{10\times10}\times\frac{2{,}160}{10\times9}=518 \text{ welds}$$

between operations in which *two* machines make a weld at the same time

Total output = 1,000 per hour

Two welds together every (518×60)/1,000 = 31 minutes

$$\frac{T}{tE}\times\frac{T}{t(E-1)}\times\frac{T}{t(E-2)}=\frac{2{,}160}{10\times10}\times\frac{2{,}160}{10\times9}\times\frac{2{,}160}{10\times8}=14{,}000 \text{ welds beween operat-}$$

tions in which *three* machines make a weld at the same time

Three welds together every 14,000/1,000 = 14 hours

Total time divided by weld time of all welders = (60×60×60) / (10×10×100) = 21.6

Interlaced Bus Calculations

The reactance values of the various wire groupings and bus-bar configurations shown in figures 2 and 3 and in tables II and III were calculated by means of the following short-cut method, utilizing the charts of reactance for a pair of conductors (either for conductors, figure 4, or standard strand cables, figure 5).[1] In this way it is possible to calculate the reactance of an interlaced bus or cable system with a reasonable degree of accuracy in a few minutes, as compared with the more laborious method based upon the fundamental relations of mutual and self-inductance which at best requires several hours.

This short-cut method of calculation is incorporated as part of this report in order that quick calculations can be made for other wire or bus configurations than those shown in the tables.

The basic methods and curves used here are not new, but were published in U. S. Bureau of Standards Scientific Paper No. 281 by Francis B. Silsbee, and also in *The Electric Journal* of June 1919 in an article entitled "Reactance Values for Rectangular Conductors" by H. B. Dwight. However, it was felt desirable to bring together all of the necessary data for the calculation of welder bus reactance and to show by actual examples the use of these data for the calculation of interlaced conductors.

The more general types of welder busses which are commonly used are: (1) four or more stranded insulated conductors interlaced and clamped together, (2) interlaced copper bars, and (3) concentric tubes. Figures 4 and 5 show the total reactance, self minus mutual, between two conductors. The same curves can be used in the following manner when more than two conductors are involved and there is an even number of conductors. Consider an interlaced bus consisting of six conductors, three going and three returning, as shown in item 15, table III, arranged as follows:

(+1) (−4) (+2) (−5) (+3) (−6)

Since the average drop of the going circuit equals the average drop of the return circuit, it is only necessary to find the drop in the going circuit and multiply it by two to determine the total circuit drop. If, as a first approximation, it is assumed that the current divides evenly between all of the going conductors, the reactance of any going conductor is the sum of the reactances of all the return conductors to the given going conductor minus the reactance of the remaining two going conductors to the given going conductor. Dividing the sum of the reactances of the going conductors by three gives the average going reactance per conductor and dividing this average by three (since it is assumed that only one-third of the current went through each conductor) gives the going circuit reactance. Multiplying this value by two gives the total circuit (going plus return) reactance.

The reactance of each going conductor can be written as follows:

$$X_1=X_{14}+X_{16}+X_{18}-X_{12}-X_{13}$$
$$X_2=X_{24}+X_{26}+X_{28}-X_{21}-X_{23}$$
$$X_3=X_{34}+X_{36}+X_{38}-X_{31}-X_{32}$$

The total circuit reactance (going plus return) is:

$$X_T=\frac{2}{9}(X_1+X_2+X_3)$$

It should be pointed out that, although this method is approximate, it is ac-

Table III. Welding Supply—Bus-Bar and Tubing Data. Calculated Data Per 100 Feet of Distance From Source to Load (200 Feet of Circuit

Item	Bars Per Leg	Spacing (See Figure 3)	Size (Inches)	Area Square Inches	Approximate Current-Carrying Capacity 35-Deg C Rise (Amperes) Open	Housing[2]	Weight (Pounds)	D-C Resistance 25 Deg C (Ohms)	Reactance (Ohms)[1]	Voltage Drop Per 1,000 Amperes 30 Per Cent Power Factor Volts	Per Cent at 480 Volts
1	1	8″ centers	¼x2	0.5	750	490	386	0.0033	0.0126	13.0	2.71
2	1	8″ centers	¼x4	1.0	1,400	950	772	0.0017	0.0098	9.84	2.05
3	1	2½″ centers	¼x2	0.5	750	490	386	0.0033	0.0072	7.86	1.64
4	1	2½″ centers	¼x4	1.0	1,400	950	772	0.0017	0.0048	5.07	1.06
5	1	1″ centers	¼x2	0.5	720	450	386	0.0033	0.0041	4.91	1.02
6	2	3″ centers interlaced	¼x2	1.0	1,400	950	772	0.0017	0.0039	4.19	0.87
7	1	1″ centers	¼x4	1.0	1,370	900	772	0.0017	0.0025	2.88	0.60
8	2x2	3″ centers interlaced	¼x3	3.0	3,600	2,600[4]	2,315	0.00056	0.0028	2.84	0.59
9	2	3″ centers interlaced	¼x4	2.0	2,600	1,800[4]	1,544	0.00084	0.0026	2.73	0.57
10	2	1″ centers interlaced	¼x2	1.0	1,350	870	772	0.0017	0.0018	2.25	0.47
11	1	½″ centers	¼x4	1.0	1,370	900	772	0.0017	0.0014	1.83	0.38
12	2	1″ centers interlaced	¼x4	2.0	2,500	1,700[4]	1,544	0.00084	0.0011	1.27	0.26
13	1	2″ Standard tube around 1¼″ extra heavy tube	1.09 0.89		800		765	0.0017	0.00078	1.25	0.26
14	1	½″ centers	¼x3	2.0	2,600	1,800[4]	1,544	0.00084	0.00076	0.98	0.20
15	3	1″ centers interlaced	¼x4	3.0	3,500	2,400[4]	2,315	0.00056	0.0007	0.83	0.17
16	1	4″ Standard tube around 3 extra heavy tube	3.18 3.05		2,000		2,410	0.00054	0.0005	0.64	0.13
17	1	½″ centers	¼x12	3.0	3,600	2,500[4]	2,315	0.00056	0.0005	0.64	0.13

NOTES: 1. Extrapolated from test data.
2. Housing material, size, and color affect rating to marked degree.
3. Reactance may be as much as 5 per cent to 20 per cent higher if bus is in magnetic housing.
4. Nonmagnetic housing.

Table IV. Chance of Simultaneous or Interfering Welds

Number of Machines	Weld Time (Cycles)	Welds Per Hour Per Machine	Total Output Per Hour	Time Interval Between Simultaneous Welds: Two Welds Together	Time Interval Between Simultaneous Welds: Three Welds Together	Number of Good Welds for Every Weld in Which Three Hit Together	Total Time Divided by Weld Time of All Welders
5	3	100	500	.52 hr	12,500 hr	6,250,000	144
5	3	200	1,000	6.5 hr	777 hr	777,000	72
5	3	300	1,500	1.9 hr	154 hr	231,000	48
5	10	100	500	4.2 hr	336 hr	168,000	43
5	10	200	1,000	35 min	21 hr	21,000	22
5	10	300	1,500	10 min	4.2 hr	6,300	14
5	30	100	300	2.9 hr	207 hr	62,300	24
5	30	200	600	22 min	13 hr	7,760	12
5	30	300	900	6 min	2.6 hr	2,310	8
5	30	100	500	31 min	12.4 hr	6,220	14
5	30	200	1,000	4 min	47 min*	778	7
10	3	100	1,000	5.8 hr	518 hr	518,000	72
10	3	200	2,000	43 min	32.4 hr	65,000	36
10	3	300	3,000	13 min	6.4 hr	19,200	24
10	10	100	1,000	31 min	14 hr	14,000	22
10	10	200	2,000	4 min	52 min*	1,745	11
10	10	300	3,000	1 min	10 min*	520	7
10	30	100	1,000	3 min	28 min*	467	7
20	3	100	2,000	41 min	27 hr	54,000	36
20	3	200	4,000	5 min	1.7 hr	6,840	18
20	3	300	6,000	2 min	20 min*	2,020	12
20	10	100	2,000	4 min	44 min*	1,480	11

*Note: On border line of unsatisfactory operating conditions if supply system is designed for ten per cent voltage drop for operation of largest machine. For these conditions supply system should probably be designed for about five per cent voltage drop.

curate within ten per cent which is good enough for most practical calculations.

Numerical Example 1. Determine the reactance of an interlaced bus 1,000 feet long, consisting of 1/4-inch by 4-inch copper bars spaced one-inch center-to-center as shown in table III, item 15. The distance between the center lines of each conductor and all of the other conductors should be calculated and the reactances corresponding to these distances should be obtained from figure 4.

For example, the distance between the center lines of conductors 1 and 4 is $1'' \times \frac{S}{a+b} = \frac{1''}{1/4''+4''} = 0.235$ and the corresponding reactance is 0.0125 ohm per 1,000 feet. The remaining reactances can be found in a similar manner.

$$X_1 = 0.0125+0.0290+0.0392-0.0220-0.0347 = 0.0240$$

$$X_2 = 0.0125+0.0125+0.0290-0.0220-0.0220 = 0.0100$$

$$X_3 = 0.0290+0.0125+0.0125-0.0347-0.0125 = -0.0027$$

$$X_T = \frac{2}{9}(X_1+X_2+X_3) = \frac{2}{9}(0.0249+0.0100-0.0027) = 0.00696 \text{ ohm (going and return)}$$

The same method can be used on stranded cables, except that the reactance values are taken from figure 5.

Numerical Example 2. Determine the reactance of six 250,000-circ-mil interlaced standard-strand, rubber-insulated cables 1,000 feet long and arranged similar to item 8, table II, arranged as follows:

(+1) (−4) (+2)
(−6) (+3) (−5)

The copper diameter is 0.576 inch, the rubber thickness is 0.094 inch, and the braid thickness is 0.020 inch, giving a total diameter of 0.804 inch. The distance between the center lines of each conductor and all of the other conductors should be calculated and the corresponding reactances should be obtained from figure 5.

The distance between the center lines of conductors 1 and 3 is $\sqrt{0.804''+0.804''} = 1.138$ inches and the corresponding reactance is 0.0368 ohm per 1,000 feet. The remaining reactances can be found in a similar manner.

$$X_1 = 0.0288+0.0288+0.0473-0.0448-0.0368 = 0.0233$$

$$X_2 = 0.0288+0.0473+0.0288-0.0448-0.0368 = 0.0233$$

$$X_3 = 0.0288+0.0288+0.0288-0.0368-0.0368 = 0.0128$$

$$X_T = \frac{2}{9}(X_1+X_2+X_3) = \frac{2}{9}(0.0233+0.0233+0.0128) = 0.0132 \text{ ohm (going and return)}$$

The reactance of concentric tubular busses is easily expressible in a formula. Let the outer radius of the outer tube be r_4, the inner radius of the outer tube be r_3, the outer radius of the inner tube be r_2, and the inner radius of the inner tube be r_1. The reactance then can be expressed as:

$$X = 11.49\ 4.606\left(\log_{10}\frac{r_2}{r_3} + \frac{r_1^4}{(r_2^2-r_1^2)^2}\log_{10}\frac{r_2}{r_1} + \frac{r_4^4}{(r_4^2-r_3^2)^2}\log_{10}\frac{r_4}{r_3}\right) - \left[\frac{r_2^2+r_1^2}{2(r_2^2-r_1^2)} - \frac{r_4^2+r_3^2}{2(r_4^2-r_3^2)}\right] \times 10^{-4}$$

where X is in ohms per 1,000 feet of bus (total going and return circuit)

Table V.—Impedance and Carrying Capacity of Conductors in One Conduit

Wire Size	Conduit Size (Inches)	Resistance One Conductor Per 1,000 Feet (Ohm)	Reactance One Conductor Per 1,000 Feet (Ohm)	Current-Carrying Capacity (Amperes) Copper, 60 Deg C Ambient, 30 Deg C
2	1 1/4	0.156	0.040	107
0	1 1/2	0.098	0.041	139
3/0	2	0.078	0.038	160
3/0	2	0.062	0.036	182
4/0	2	0.049	0.038	210

Feeder Data for Small Installations

In cases of small installations of welders served at low voltage (240 or 480 volts) by the power company the plant wiring will generally consist of wires pulled in conduit. It is usually unnecessary to lace the going and return wires together for minimum spacing before pulling in conduit, as the natural positioning of the wires in the conduit will give close enough spacing.

Table V gives the impedances of circuits and current-carrying capacities of relatively small wires suitable for small installations.

Typical Examples

Example 1. Small Job-Welding Shop

Machines:
One 150-kva seam welder
Four 20-kva spot welders

Maximum kilovolt-ampere load swing of largest machine:
1,500 amperes at 240 volts = 360 kva

Regulation for 360 kva:	Per Cent
1. Supply system (4,800 volts)	3.0
2. 200-kva, single-phase, 4,800/240-volt, 3-per-cent, Z transformer	5.5
3. 100 feet two 4/0 wires per leg in conduit	2.3
Total	10.8

Equivalent continuous thermal loading:
0.7×150 kva = 105
0.1×4×20 kva = 8

113 kva = 470 amperes at 240 volts

Example 2. Small Job-Welding Shop

Machines:
Three 50-kva spot welders
Two 150-kva press welders
One 200-kva projection welder

Maximum kilovolt-ampere load swing of largest machine:
2,100 amperes at 240 volts = 500 kva

Regulation for 500 kva:	Per Cent
1. Supply system (4,800 volts)	4.1
2. 500-kva, single-phase, 4,800/240-volt, 3-per-cent, Z transformer	2.9
3. 150 feet one $\frac{1}{4}$-inch by 4-inch bar per leg, 1-inch centers	3.7
Total	10.6

Equivalent continuous thermal loading:
10 per cent×650 kva = 65 kva = 270 amperes at 240 volts

Example 3. Small Manufacturing Plant

Machines:
Five 250-kva press welders
Two 50-kva spot welders
Eight 30-kva spot welders

Maximum kilovolt-ampere load swing of largest machine:
825 amperes at 485 volts = 400 kva

Regulation for 400 kva:	Per Cent
1. Supply system (24,000 volts)	1.1
2. 700-kva, single-phase, 24,000/485-volt, 13-per-cent, Z transformers	7.4
3. 150 feet one $\frac{1}{4}$-inch by 2-inch bar per leg, $2^1/_4$-inch centers	2.0
Total	10.5

Equivalent continuous thermal loading:
Practically all three-cycle welding so use about five per cent of sum of connected load
0.05×1,590 kva = 80 kva = 165 amperes at 485 volts

Example 4. Small Manufacturing Plant

Machines:
Two 150-kva projection welders (automatic feed)
One 75-kva spot welder
One 50-kva spot welder
Eleven 25-kva portable welders

Maximum kilovolt-ampere load swing of largest machine:
850 amperes at 240 volts = 205 kva

Regulation for 205 kva:	Per Cent
1. Supply system (4,800 volts)	2.7
2. 600-kva, three-phase, 4,800/240-volt, 5-per-cent, Z power transformer bank	3.4
3. 170 feet two 4/0 wires per leg in conduit	2.6
Total	8.7

Equivalent continuous thermal loading:
150-kva projection welder
2,000 welds per hour—3-cycle welds
Duty cycle = (2,000×3)/(60×60×60) = 2.77 per cent
200 kva at 2.77 per cent duty cycle = 34 kva continuous
Two machines = 2×34 = 68 kva continuous
Remaining machines, 10 per cent×400 = 40 kva
Total. 108 kva

Example 5. Large Manufacturing Plant

Location *A*. Connect to Phase *AB*

Machines:
Three 550-kva butt welders
One 500-kva projection welder
One 400-kva projection welder
Three 150-kva projection welders

Maximum kilovolt-ampere load swing of largest machine:
2,700 amperes at 480 volts = 1,300 kva

Regulation for 1,300 kva:	Per Cent
1. Supply system (4,800 volts)	5.6
2. Three 500-kva, single-phase, 4,800/480-volt, $3^1/_2$-per-cent, Z transformers	3.0
3. 125 feet two $\frac{1}{4}$-inch by 4-inch bars per leg, interlaced $2^1/_4$-inch centers	1.7
Total	10.3

Equivalent continuous thermal loading:
550-kva butt welder
200 welds per hour—30-cycle welds
Duty cycle = (200×30)/(60×60×60) = 2.77 per cent
1,300 kva at 2.77 per cent duty cycle = 216 kva continuous
Three machines = 3×216 = 648 kva continuous
Remaining machines, 10 per cent × 1,350 = 135 kva
Total, 783 kva = 1,670 amperes at 480 volts

Location *B*. Connect to Phase *BC*

Machines:
40 hydromatic welders, 150 to 300 kva each
Total connected load = 7,000 kva

Maximum kilovolt-ampere load swing of largest machine:
2,100 amperes at 480 volts = 1,000 kva

Regulation for 1,000 kva:	Per Cent
1. Supply system (4,800 volts)	4.1
2. Two 500-kva, single-phase, 4,800/480-volt, $3^1/_2$-per-cent, Z transformers	3.5
3. 200 feet two $\frac{1}{4}$-inch by 4-inch bars per leg, interlaced $2^1/_4$-inch centers	1.9
Total	9.5

Equivalent continuous thermal loading:
15 per cent×7,000 kva = 1,050 kva = 2,200 amperes at 480 volts

Location *C*. Connect to Phase *CA*

Machines:
Two 700-kva butt welders
Two 500-kva butt welders

Maximum kilovolt-ampere load swing of largest machine:
3,500 amperes at 480 volts = 1,670 kva

Regulation for 1,670 kva:	Per Cent
1. Supply system (4,800 volts)	6.9
2. Three 500-kva, single-phase, 4,800/480-volt, $3^1/_2$-per-cent, Z transformers	4.0
3. 150 feet two double $\frac{1}{4}$-inch by 3-inch bars per leg, interlaced 3-inch centers	3.1
Total	14.0

The two 700-kva machines were interlocked so that they could not be operated together and the two 500-kva machines were also interlocked.

Equivalent continuous thermal loading:
700-kva welder
100 welds per hour—$2^1/_2$ second welds
Duty cycle = (100×$2^1/_2$×60)/(60×60×60) = 6.95 per cent
1,670 kva at 6.95 per cent duty cycle = 440 kva
Two machines = 2×440 = 880 kva
500-kva welder
100 welds per hour—2 second welds
Duty cycle = (100×2×60)/(60×60×60) = 5.55 per cent
1,200 kva at 5.55 per cent duty cycle = 283 kva
Two machines = 2×283 = 566 kva
Total, 880+566 = 1,446 kva

Reference

1. Reactance Chart for Welder Bus Problems, R. C. Bouse and J. D. Scarbrough. *Electrical World*, volume 115, No. 10, March 8, 1941 page 106.

Discussion

Discussion will be found in the 1941 annual Transactions volume and in the December 1941 Supplement to Electrical Engineering—Transactions Section.

A Conserved-Pressure Air-Blast Circuit Breaker for High-Voltage Service

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Synopsis: This paper describes the design and construction of a 138-kv, 1,500,000-kva air-blast circuit breaker. The construction is made possible by the use of a new interrupting device which utilizes the axial blast nozzle together with a "conserved pressure" chamber. The chamber receives the exhaust from the interrupting nozzle and contains the movable contact of the breaker in its open position. By means of a spring-loaded relief valve the pressure and dielectric strength of the air in the chamber are maintained at a high level.

The pressure in the chamber is at the same time less than 50 per cent of the pressure above the nozzle restriction so that the air flow through the interrupting nozzle is unimpaired, being the same as through the same nozzle discharging to atmospheric pressure. As a consequence, the conserved pressure breaker is found to have the same ability to interrupt current as a conventional axial nozzle but to be capable of interrupting circuits of much higher voltage.

The 138-kv three-phase breaker consists of two interrupting units in series per pole with a disconnecting device included as part of the breaker. Operation of the breaker is entirely pneumatic, opening and closing being performed by energizing the electrically operated valve.

Interrupting Unit

TWO distinct types of air-blast interrupting units have previously been described, the cross blast,[1,2,4] in which air is directed across the arc formed in the path of the separating contacts, and the axial blast in which air flows through an orifice in the direction of the moving contacts.

Data[1] published at the 1940 midwinter convention showed that the European axial blast unit required a volume of air for interruption that was proportional to the maximum current interrupted. As a consequence such a breaker would require excessive quantities of air if it were built in the ratings found in this country. The problem of interrupting these high currents, of as much as 100,000 amperes, was solved by the introduction of the cross-blast unit which makes very economical use of air.

For high-voltage service, however, the currents to be interrupted are relatively light and the interruption problem is one of voltage magnitude. Under these conditions, the axial nozzle shows more promise for it is naturally a better insulating structure than the cross-blast breaker. Since it is cylindrical it may be turned from a solid piece of insulating material and it can be readily accommodated inside of a porcelain insulator.

However, the straight axial nozzle was found to have limited voltage-interrupting capacity and it was through a study of these limits that the conserved pressure interrupter was developed. The conserved pressure breaker is a solution to the problem of interrupting relatively light currents at high voltage. Its development and a direct comparison between it and two axial nozzles will be described.

A simple form of the axial-blast interrupting unit which has been used in Europe is illustrated by figure 1. In this design high-pressure air flows around the cylindrical stationary contact and expands to the atmosphere through the nozzle from which the moving contact has been withdrawn. The moving contact is drawn out into the open air and in the fully open position comes to rest in a region of atmospheric pressure.

Figure 2 illustrates the variation of the dielectric strength of air as a function of pressure. As a consequence of this variation, the dielectric strength of the air at the fixed contact of the breaker is five or six times as great as at the moving contact whereas, depending upon the interrupter configuration, the voltage gradient in the low-pressure area may be as high as in the high-pressure region. As the voltage rises, after the current has been momentarily interrupted by the air blast, the moving contact then provides a starting point for an electrical breakdown between the contacts.

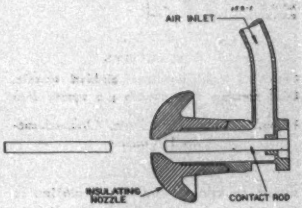

Figure 1. European high-voltage air-blast nozzle

This dielectric breakdown between the contacts can be avoided by a nozzle configuration of the type shown in figure 3A. Such a nozzle extends the region of high pressure—high dielectric-strength air to such a length that the contact spacing can withstand a high-applied voltage in spite of the fact that the air at the end of the moving contact is overstressed.

The interrupting ability of this long

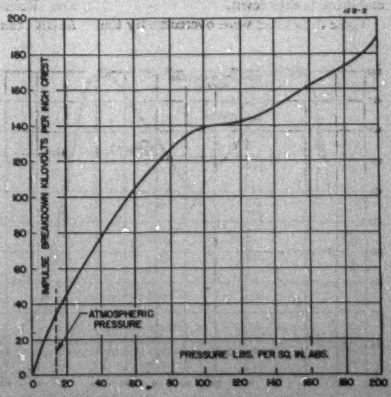

Figure 2. Impulse breakdown of a two-centimeter rod gap in air as a function of pressure. Temperature 25 degrees centigrade

Paper 41-58, recommended by the AIEE committee on protective devices, and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted November 28, 1940; made available for preprinting December 13, 1940.

R. M. BENNETT is in the circuit breaker development division of the General Electric Company, Philadelphia, Pa.; W. R. RANKIN is also employed by this company.

1. For all numbered references, see list at end of paper.

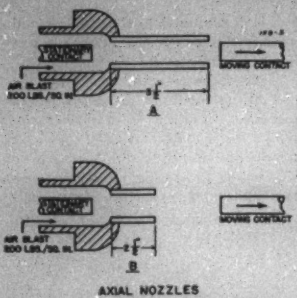

Figure 3. High-voltage air-blast nozzle. Inlet pressure 200 pounds per square inch

Exhaust pressure—atmospheric. Orifice diameter $1\frac{1}{4}$ inches

nozzle, in kilovolt-amperes, is plotted in figure 4 as a function of voltage. It is to be noted that although the breaker can interrupt a relatively large kilovolt-ampere at 38 kv, it has a definite current limit, so that, at lower voltages, where a larger current must be interrupted for a given kilovolt-ampere, the breaker fails. That is, the large volumes of ionized gas produced by large currents cannot be discharged by the long-restricted nozzle with sufficient rapidity to permit interruption.

The nozzle of figure 3*B* represents another extreme. It consists of little more than an orifice and is consequently capable of interrupting considerable current at low voltage. See figure 4. However, after interruption of the current at high voltages, progressive dielectric breakdown proceeds from the overstressed air at the tip of the moving contact back toward the orifice to such an extent that the high-pressure air becomes overstressed and it too breaks down.

These difficulties were overcome by the conserved pressure design which permits the moving contact to remain in a region of high-pressure air after the contacts have separated.

Figure 5 is a schematic representation of the breaker. High-pressure air is supplied from below, flows around the stationary contact and expands through an orifice to a chamber surrounding the moving contact. Pressure in this chamber is maintained at approximately 100 pounds per square inch by means of a spring-loaded relief valve. Provided the pressure in the chamber does not rise above approximately 53 per cent of the pressure above the orifice, the velocity and density of the air blast are unaffected by the pressure. It would therefore be expected that the performance of the conserved pressure breaker would be similar to that of the short orifice with the exception that it could interrupt much higher voltages. The dashed curve of figure 4 confirms this fact.

Breaker Construction

Each phase of the 138-kv air-blast circuit breaker consists of two conserved pressure-type interrupting units in series. The breaker which is rated 1,500,000 kva is supplied with air at 350 pounds per square inch.

The schematic drawing figure 6 shows the general arrangement of a single pole of the breaker. See figure 7. The essential parts consist of a main-blast valve for admitting air to the interrupters, an interrupting unit, a disconnect, and a mechanism for operating the disconnect.

The three-phase breaker has a main-air blast valve for each phase of the breaker. These are of the same type as the valves used in the 15-kv air-blast breakers described by Messrs. Strang and Boisseau at the 1940 midwinter AIEE convention.[3] They are poppet-type valves actuated by a piston which in turn is operated by air from a solenoid-operated differential pilot valve. The valves have an over-all operating time of two cycles from the time the solenoid coil is energized until the valve is completely open.

The interrupting contacts are separated by the action of the main air blast and are returned to the closed position by springs as soon as the air blast is turned off. Consequently a disconnect is provided, the function of which is to provide a clear air break after interruption is complete and before the interrupting contacts return to their closed position.

Closing of the breaker is performed by closing the disconnect. The closing speed of the breaker is not materially affected by current magnitudes in excess of the minimum breaker rating. This is accounted for by the fact that in the 138-kv breaker, the maximum rated current is a relatively light 9,500 amperes so that the magnetic forces are small compared with the inertia of the disconnect assembly.

The interrupting units are entirely pneumatic in operation, and require no mechanical connection with ground. The main air blast acts on a piston which is integral with the moving contact to move the upper contact upward separating the contacts.

When the movable contact has been withdrawn from the nozzle restriction the air blast which follows sweeps the contact space free of ionized gas at a current zero. The 138-kv breaker uses two interrupters in series, the total contact motion of each being eight inches. The interrupting contacts are returned by springs to the closed position as soon as the blast valve closes.

The interrupting nozzle is turned from a block of insulating material similar to fiber in possessing the property of becoming volatile at moderate temperatures. In the presence of an arc this property prevents the deposit of carbon on the surface of the nozzle and at the same time the gas which is evolved prevents the nozzle surface from reaching the high temperatures at which many otherwise

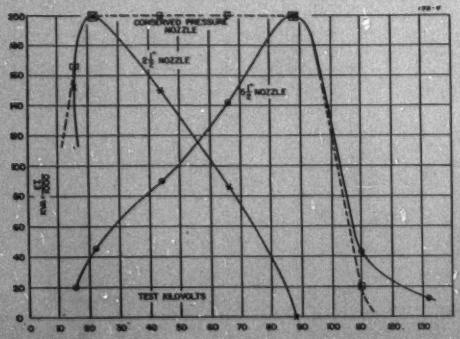

Figure 4. Interrupting ability of high-voltage air-blast nozzles. Inlet pressure 200 pounds per square inch. Maximum recovery rate 2,500 volts per microsecond

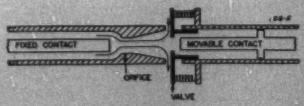

Figure 5. Schematic diagram of conserved pressure-interrupting unit

Inlet pressure 200 pounds per square inch. Orifice diameter $1\frac{1}{4}$ inches

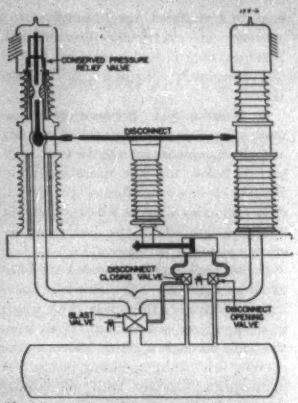

Figure 6. Schematic diagram of a single pole of the 138-kv, 1,500,000-kva air-blast circuit breaker

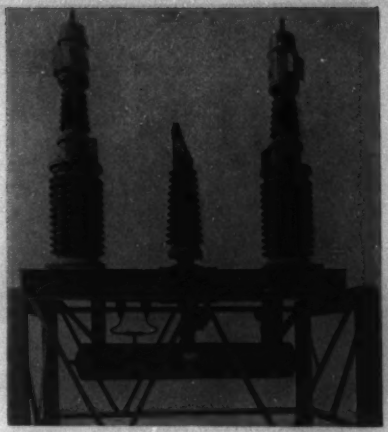

Figure 7. A single pole of the 138-kv, 1,500,000-kva air-blast circuit breaker

good insulators become conductors. The nozzle is contained in a herkolite tube which supports the upper contact piston and the conserved pressure-relief valve. The tube in turn is contained in a porcelain insulator.

The disconnect is also supported by a porcelain insulator which was specially developed for the purpose. The porcelain instead of having a straight creepage path inside, requiring that it be oil-filled and sealed, is made of a number of sections fused together. Each section is shaped like a cylinder closed at one end. When the sections are stacked up to form the insulator the closed ends of the sections become solid partitions across the inside of the insulator.

The disconnect arm engages long sliding stationary contacts by means of a

Table I. Single-Phase Opening and Closing-Opening Tests of AR-30-150, 138-Kv, 1,500,000-Kva Air-Blast Circuit Breaker

Test Number	Service	Single-Phase (Kilovolts)	RMS Amperes		Trip Impulse to Interruption (Cycles)	Recovery Voltage		Air Pressure in Tank
			Maximum Loop Closing	Initial in Arc		Rate of Rise	Peak Value (Kilovolts)	
1	O	132		40	5.2	590	290	300
2	O	132		43	4.9	630	320	300
3	O	132		470	5.7	1,420	320	300
4	O	132		720	5.7	1,600	360	300
5	O	132		890	6.0	2,000	290	300
6	O	132		1,150	5.5	2,000	290	300
7	O	132		1,280	6.5	2,200	310	300
8	O	132		1,420	5.7	2,400	280	300
9	O	88		750	4.9	1,300	200	300
10	O	88		1,330	5.7	2,100	220	300
11	O	88		1,880	5.5	2,400	180	300
12	O	88		2,100	5.5	2,500	190	300
13	O	66		2,900	5.3	2,400	110	300
14	O	44		3,800	5.4	1,900	82	300
15	O	44		4,400	4.8	1,900	75	300
16	O	22		6,900	5.0	1,000	36	300
17	O	22		7,700	5.2	1,100	38	300
18	O	22		9,700	5.5	1,100	33	300
19	O	22		10,700	5.5	1,100	33	300
20	O	22		9,500	5.5	710	30	300
21	O	132		80	4.4	1,410	373	300
22	O	132		670	5.2	3,100	312	300
23	O	132		1,100	5.5	4,100	261	300
24	O	132		1,500	5.0	4,500	261	300
25	CO	132	61	61	4.5	430	230	350
26	CO	132	690	660	5.5	1,700	300	350
27	CO	132	1,180	970	5.0	1,900	240	350
28	CO	132	1,490	1,190	5.0	2,000	250	350
29	CO	132	1,810	1,390	5.2	2,100	240	350
30	CO	132	2,300	1,610	5.2	2,300	250	350
31	CO	88	84	84	4.3	780	210	300
32	CO	88	3,500	2,600	5.0	2,500	150	300
33	CO	88	5,300	3,600	5.0	2,500	192	300
34	CO	44	4,800	3,900	5.4	1,800	83	300
35	CO	44	4,900	4,300	4.7	1,800	74	300
36	CO	22	10,200	7,500	4.8	930	36	300
37	CO	22	11,300	8,100	4.7	980	37	300
38	CO	22	10,000	8,500	5.2	1,100	37	300
39	CO	22	13,600	9,500	5.2	1,000	33	300

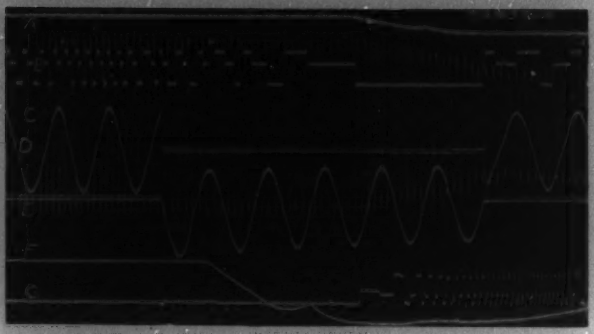

Figure 8. Test number 30. Table I. Single-phase closing-opening operation at 132 kv

Curve *A*—Disconnect trip impulse
Curve *B*—Disconnect travel—0.67 inch per step
Curve *C*—Pressure in interrupting chamber
Curve *D*—Voltage at breaker terminals
Curve *E*—Current through breaker
Curve *F*—Air-blast trip-coil current
Curve *G*—Interrupting contact travel—0.1 inch per step

loose-hinged blade which twists as it disengages. The contacts are so shaped that the arc formed during closing burns heavy contact tips rather than the contact surfaces. Both opening and closing of the disconnect is performed by a double-ended pneumatic piston which acts to rotate, about a vertical axis, the whole assembly, consisting of disconnect arm and insulator.

Air Auxiliaries

Air is supplied to the breaker tank from a conventional electric motor-driven storage and compressor unit. To eliminate the possibility of moisture reaching the breaker a compression cycle is used to dry the air.

Air is compressed to 1,000 pounds per square inch, cooled so that moisture is condensed in the high-pressure chamber, and is expanded to 350 pounds per square inch. After expansion the dew point of the air is approximately 80 degrees Fahrenheit below the temperature of the ambient air.

The control for the expansion valves is by means of Bourdon-type pressure switches. The control is arranged so that no air expands from the 1,000-pound tank to the 350-pound tank unless the compressor has brought the high-pressure tank up to full pressure. Thus no air can flow into the 350-pound tank unless it has gone through the complete compression cycle.

Operation

A breaker-opening operation is performed by electrically energizing the three-blast valve solenoids in parallel. The three valves are pneumatically interconnected so that all three main blast valves can be opened by any one of the solenoid-operated pilot valves. Opening of the blast valves initiates two functions. First, an air blast is supplied to the interrupting units to separate the contacts and interrupt the arc. Second, air is supplied to the disconnect control to initiate opening of the disconnects. The disconnect control is pneumatically interlocked with the blast valves so that the disconnect cannot operate unless all three blast valves have opened. If all three blast valves open, air is admitted to a differentially-operated pilot valve which in turn admits air directly from the tank to the disconnect operating piston. Separation of the disconnect contacts is timed to take place after the arc has been interrupted. Once the opening operation has been initiated the closing control solenoid is electrically disconnected. Electrical control is also provided so that the disconnect operation can be prevented.

A Bourdon-type pressure switch is used to open both the electrical opening and closing circuits in case the tank pressure is below the safe operating limit. Breaker closing is performed by electrically energizing a valve which admits air to the closing side of the disconnect operating piston.

Rapid reclosing is provided as indicated by figure 9. The disconnect opening pilot valve is a three-way valve which in the energized position admits air from the tank through a dump valve to the opening side of the operating piston. A light spring together with air flowing through the dump valve in the direction of the operating cylinder holds the dump valve closed.

When the pilot valve is de-energized, however, it opens a passage, from the back of the dump valve to the atmosphere, permitting the dump valve to open and exhaust the air from the opening side of the disconnect operating piston. Trip-free operation is provided by using the same valve arrangement for the closing side of the disconnect.

A complete closing-opening operation of the breaker takes place in the following order. Starting with the interrupting contacts closed and the disconnect open,

1. Disconnect solenoid energized.
2. Disconnect closes.
3. Disconnect solenoid de-energized.
4. Blast-valve solenoid energized.
5. Blast valve opens.
6. Disconnect opening pilot energized by air blast.
7. Interrupting contacts parted by air blast and arc interrupted.
8. Disconnect opens.
9. Blast valve de-energized.
10. Interrupting contacts return to closed position.

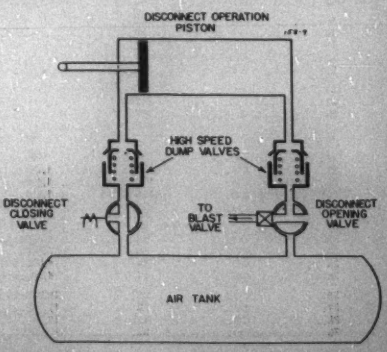

Figure 9. Disconnect operating mechanism

A New Air Circuit Breaker With 250,000-Kva Interrupting Capacity

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Synopsis: Heretofore it has not been commercially feasible to apply air-type breakers of the 5,000-volt class to circuits capable of producing short-circuit currents equivalent to 250,000 kva. However the continued demand for air circuit breakers of higher interrupting ratings has stimulated the development of a new breaker suitable for these applications. This achievement has been accomplished through magnetically enhanced diffusion of ionized particles, establishing dielectric strength in a gaseous region which was previously highly conducting. The interrupter consists essentially of an arc chamber of laterally spaced refractory plates embodying V-shaped slots and a magnetic circuit which imposes an intense magnetic field transverse to the slotted plates during the arcing period.

The theory of arc interruption by this new air breaker is considered. Design details are described and illustrated. Complete sets of test results are given, with representative oscillograms. The test results are discussed, and it is demonstrated that the new breaker is applicable to modern metal-clad switchgear.

I. Introduction

THE advantages of air-type power switching equipment are becoming increasingly apparent to the electrical industry. The result is a general desire to be able to supply air circuit breakers over the entire range of applications which have become established by the use of oil-type switching equipment. In response to the demand to fill in the gaps in the established interrupting ratings with air circuit breakers, a new self-contained unit suitable for an interrupting rating of 250,000 kva at five kv has been developed.

Early in 1938 development of principles somewhat different from those of the original "De-ion" air breakers[1] resulted in devices having very high-current interrupting ability at moderate voltages.[2] Currents as high as 120,000 amperes at 750 volts were interrupted. The principle of operation is a combination of arc construction and rapid gas motion. The gas motion is produced by virtue of a self-induced magnetic field which imparts a net upward component of velocity to the conducting electrons. The arcing time is definitely limited to one-half cycle or less.

The scope of this principle of magnetic deionization was expanded to devices having 150,000-kva interrupting ratings at 2,500 and 5,000 volts.[3] Continuation of the development has resulted in still further application of magnetically enhanced diffusion of ionized particles. The following sections are devoted to describing the newly developed air circuit breaker having an interrupting rating of 250,000 kva at 4,000 to 5,000 volts.

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1. For all numbered references, see list at end of paper.

II. Design of the Interrupter

In addition to meeting the current carrying and interrupting requirements, an air circuit breaker should have a space factor comparable to the similarly rated oil breaker. The problem is then one of suitably drawing and enclosing the arc and controlling the ionized gases and other by-products of arc interruption. It has been found that definite advantages exist in utilizing a relatively short arc and permitting the current of the arc in interruption to go to its normal zero in cycle—whereat intensive deionization is provided to establish dielectric strength. The method of magnetic deionization possesses this type of arc characteristic.[3]

An extended series of tests, table I, made on a standard 150,000-kva 5,000-volt breaker demonstrated that there was a wide margin of safety above the 150,000-kva rating. Hence the logical program was to continue development of this design.

It had been indicated that the voltage which could be interrupted was very nearly proportional to the number of refractory plates in the arc chamber. Further, the amount of current that could be interrupted was a function of the plate width and thickness and of the vent space between the plates. Hence for the five-kilovolt ratings, two refractory sections or twice the number of insulating plates were necessary. In order to bring the arc uniformly into the V-shaped slots of all the plates the structure was supported at sufficient height above the arcing contacts to permit the use of sloping arc horns. See figure 1. The added arc length and distance of arc travel required greater venting to exhaust and deionize the hot gases. The vents between the refractory plates were made more effective by using wider and longer plates and by stacking them farther apart. A space was provided intermediate to the two refractory sections to release the initial gas pressure and to stabilize the arc during current interruption. Figure 2 is a picture of the two sections of refractory plates taken from a 250,000-kva 5-kv arc chamber.

During short-circuit operation of the magnetic "De-ion" breaker an arc is drawn between the separating arcing contacts, and is looped upward, magnetically, into the V-shaped slots. By transfer of the arc to the panel-end horn (figure 1),

Interrupting Tests

The 138-kv, 1,500,000-kva breaker is required to interrupt 6,300 amperes at rated voltage which is approximately 80 kv line to neutral. The maximum current rating is 9,500 amperes.

Table I is a series of single-phase interrupting tests performed on a single pole of the breaker. The currents interrupted range from light currents, similar to line-charging currents, to a maximum of 10,700 amperes.

Rates of rise of recovery voltage up to 4,500 volts per microsecond have been interrupted at 132 kv.

Figure 8 is a magnetic oscillogram of the closing-opening operation of test number 30.

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4. MEDIUM-CAPACITY AIR-BLAST CIRCUIT BREAKERS FOR METAL-CLAD SWITCHGEAR, R. M. Bennett and B. W. Wyman. AIEE TRANSACTIONS, volume 60, 1941.

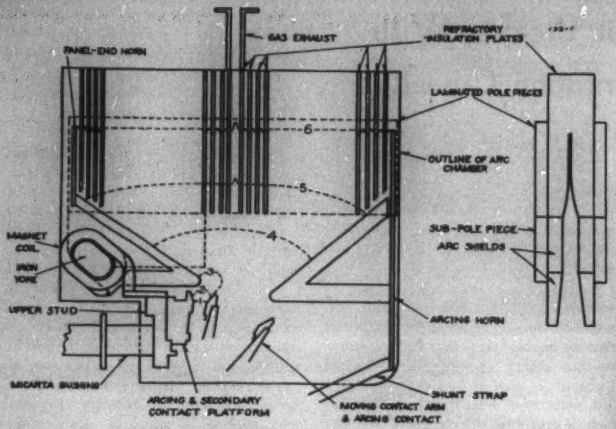


Figure 1. A diagrammatic sketch showing partial sections of the 5,000-volt magnetic "De-ion" interrupter. The dotted lines 1, 2, 3, 4, 5, and 6 indicate progressive positions in arc interruption

the magnet coil is switched into the circuit, thus imposing a strong transverse magnetic field. The upward motion of the arc is impeded by the refractory plates; however, a net upward component of velocity is imparted to the conducting electrons. They in turn bombard gas particles and produce a rapid flow of gas perpendicular to the arc. This reaction enhances the diffusion of the ionized gas particles and continuously causes the arc to ionize fresh gas in considerable quantities. The deionizing action is particularly prevalent near the edges of plates, and it continues in a sufficient degree to establish high dielectric strength during the period of relative low recovery voltage following a current zero.

By this method of magnetically enhanced diffusion of ionized gas particles the effectiveness and life of the interrupter are preserved. The long series of tests listed in tables II and III are typical runs which have not produced excessive wear on either the arc chamber plates or breaker contacts.

Figure 2. Two ceramic sections taken from an arc chamber after a series of 19 interrupting tests at 3,830 volts restored, single phase, and currents equivalent to 192,000 to 306,000 kva three phase

III. The Breaker Mechanism

The contact system and electromagnetic operating mechanism of the magnetic "De-ion" breakers are specially designed for high speed. Fast operation promotes both better contact protection and one-half cycle arcing time for currents of short-circuit values. Low inertia of the movable contact is obtained by a pivotally mounted contact arm upon which a pair of secondary and arcing contacts are rigidly attached to protect the main contact member. This main contact member is a solid copper block having heavy silver-inlay contacts. The arcing and secondary contacts are a silver-tungsten cintered mixture which is highly resistant to arcing. Figure 3 is a picture of a beaker with its contacts in open position.

A standard three-pole 5,000-volt breaker is shown in figure 4. The barrier structure is a plain interphase arrangement pivotally mounted as a unit at the

Figure 3. A 5-kv 2,000-ampere magnetic "De-ion" breaker with the unit interphase barrier and left-pole arc chamber removed to show the contacts and magnet coil

Figure 4. Complete draw-out type of magnetic "De-ion" breaker for five-kilovolt service

lower front corner. The unit is simply removed by pulling the top forward and lifting the assembly from its pivots.

The arc chambers are removable units supported by the laminated pole pieces. An individual chute assembly is shown in figure 5. The connectors of the arcing horns are automatically engaged when the arc chamber is pushed back into position on the laminated pole pieces.

The trip-free operating mechanism is mounted in a horizontal position immediately below the lower studs and moving contacts. It is isolated from the live parts by a steel barrier, and actuates the contacts through suitable insulating push rods. See figure 3.

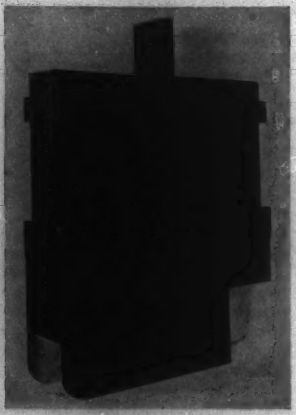


Figure 5. The arc-chamber unit of a magnetic "De-ion" breaker

An air dashpot is directly coupled to the operating lever of the mechanism. The volume of air handled is sufficient to absorb the kinetic energy of the opening contacts at both no-load and short-circuit capacity, thus bringing the contacts to a gentle rest without impairing the opening speed for approximately 50 per cent of the contact travel. The air dashpot is clearly shown in figure 4.

The magnetic "De-ion" breaker is designed to meet the requirements of modern metal-clad switchgear. Figure 6 illustrates the standard arrangement of the entire line of magnetic "De-ion" breakers for 2.5 to 5 kv, 600 to 2,000 amperes and up to 250,000-kva interrupting rating at 5 kv. The width of the 100,000- and 150,000-kva 3-pole breakers is 21 3/8 inches, and that of the 250,000-kva 5-kv unit is 31 inches.

Figure 6. Horizontal draw-out metal enclosed switchgear unit with a magnetic "De-ion" breaker for 2.5 to 5 kv, 600 to 2,000 amperes and up to 250,000-kva interrupting rating

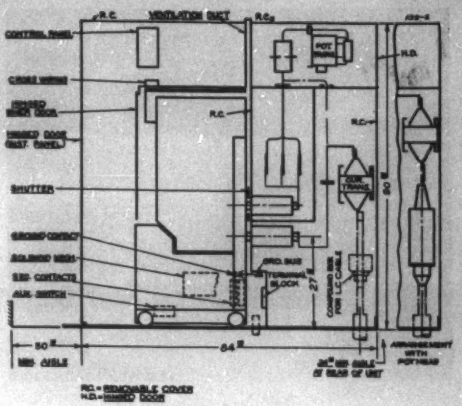


Table I. Typical Data From Interrupting Tests on a Single Pole of a 5,000-Volt 150,000-Kva Magnetic "De-ion" Breaker

Test Number	Test Voltage	RMS Amp. Interrupted	Arcing Time Cycles	Equivalent 3-φ Mva
1	3,300	27,000	1/2	154
2	3,500	28,500	1/2+	173
3	3,700	19,200	1/2	123
4	3,900	17,500	1/2−	118
5	4,100	18,600	1/2	132
6	4,300	25,000	1/2	186
7	4,500	18,600	1/2	145
8	4,700	19,400	1/2	158
9	5,000	10,000	1/2	52
10	4,900	18,000	1/2−	152
11	4,900	15,300	1/2	130
12	4,900	16,700	1/2−	142
13	5,000	16,000	1/2	139
14	5,000	600	.4	
15	5,000	550	.4	
16	5,000	380	.5	
17	5,000	400	.5	
18	5,000	360	.5	
19	3,000	13,300	1/2	69
20	3,500	13,900	1/2−	84
21	4,000	13,300	1/2	92
22	4,300	16,500	1/2	123
23	4,500	14,500	1/2	113
24	4,700	15,800	1/2−	128
25	4,900	17,800	1/2	151
26*	5,000	16,800	3/4	146
27	5,000	18,600	1/2+	161
28*	5,000	16,000	1/2	139
29	5,000	16,000	1/2−	139
30	5,000	19,000	1/2	165
31	5,000	20,000	1/2+	173
32	5,000	19,400	1/2	168
33	4,000	19,400	1/2−	134
34*	4,000	18,800	1/2−	130
35*	4,000	20,500	1/2	144
36	4,000	22,600	1/2+	157
37	4,000	26,000	1/2	180
38	4,000	30,500	1/2−	211
39	4,000	26,500	1/2+	184
40	4,000	24,000	1/2−	166
41	4,000	26,000	1/2+	180
42	4,000	33,500	1/2	232
43	4,000	21,800	1/2−	151
44	4,000	23,500	1/2	163
45	4,000	30,500	1/2−	211
46	4,000	26,500	1/2	184
47*	4,000	24,000	1/2	166
48	4,200	37,000	1/2	269
49	4,200	31,300	1/2+	228

*Oscillograms of these tests are shown in figure 7.

Current interrupted, amperes				
16,800	16,000	18,800	20,500	24,000
Restored volts				
4,600	4,700	3,750	3,640	3,800

Figure 7. Representative oscillograms of tests listed in table I

Current interrupted, amperes				
24,800	39,900	25,900	36,800	25,900
Restored volts				
3,830	3,800	3,830	3,890	3,950

Figure 8. Representative oscillograms of tests listed in table II

IV. Test Results

Extended series of tests were made during the development of the 250,000-kva 5-kv magnetic "De-ion" breaker. In addition to demonstrating ample margin for an interrupting rating of 250,000-kva at 5 kv, these numerous tests have shown the continued effectiveness of the breaker when applied to repetitious duty at and above the interrupting rating. Indeed, the wear on the contacts and arc chamber parts is small even after many operations, and the functioning of the breaker is in no way impaired.

Table I illustrates a typical run of 49 consecutive interrupting tests made on a single pole of a 5-kv 150,000-kva breaker without service to the breaker or arc chamber. The short-circuit values ranged from load currents to 37,000 amperes (equivalent to 291,000 kva, 3-phase). Figure 7 is a picture of five oscillograms taken from the tests listed in table I.

A short run of 19 interrupting tests with currents as high as 306,000 kva is indicated in table II. Figure 8 shows representative oscillograms from the group. These tests were made on a 5-kv 250,000-kva breaker, causing very little wear upon the arc chamber parts. The two individual ceramic sections of this chute are shown in figure 2.

A series of 34 short-circuit tests were made on a similar 5-kv 250,000-kva arc chamber. These tests are listed in table III, and the starred data are illustrated by the oscillograms of figure 9. The data indicate considerable margin above the interrupting rating of 250,000 kva.

During another series of tests on a single pole of a 5-kv 250,000-kva breaker two consecutive shots of 300,000 kva 3-phase were obtained. The severity of these interruptions did not stress the interrupter unduly. The oscillograms are shown in figure 10.

Numerous interrupting tests have been made at lower current values with five kilovolts across a single pole. These low currents were obtained by connecting an air-cored reactor of negligible resistance directly in series with the breaker and a 20,000-kva generator. At 1.6 amperes the arc was interrupted in less than one-half cycle. The arcing time-current characteristic rises gradually to about 22 cycles at 14 to 20 amperes and recedes to 4 cycles at 600 amperes. At currents above several thousand amperes the arcing time is only one-half cycle.

The magnetic "De-ion" breaker is applicable to circuits requiring repetitious switching. No-load *CO* life tests have been made in excess of 25,000 operations without repair to any part. At the close of the tests there was no indication of wear or strain on the breaker which would require overhauling or replacement of any major item.

Table II. Typical Data From Interrupting Tests on a Single Pole of a 5,000-Volt 250,000-Kva Magnetic "De-ion" Breaker

Test Number	Test Voltage	RMS Amp. Interrupted (Thousands)	Arcing Time Cycles	Equivalent 3-φ Mva
1	4,000	29.0	½−	201
2	4,300	33.6	½	250
3	4,300	35.0	½+	261
4	4,300	28.0	½	209
5	4,300	31.2	½−	232
6	4,300	24.8	½	185
7	4,300	37.8	½−	282
8*	4,300	24.8	½	185
9	4,300	27.4	½	204
10*	4,300	39.9	½+	297
11	4,300	24.8	½+	185
12	4,300	24.8	½	185
13	4,300	26.4	½+	197
14*	4,300	25.9	½−	193
15*	4,300	36.8	½+	274
16	4,300	27.4	½	204
17	4,300	26.4	½	197
18	4,300	27.4	½−	204
19*	4,300	25.9	½−	193

*Oscillograms of these tests are shown in figure 8.

V. Conclusions

The principle of magnetically enhanced diffusion of ionized particles for establish-

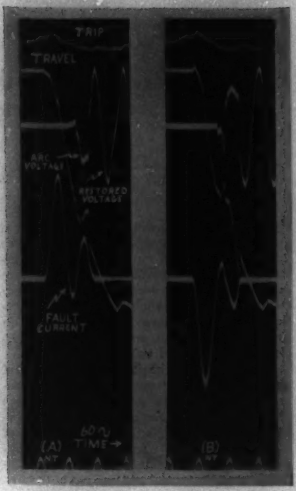
Figure 9. Oscillograms of tests indicated in table III

Current interrupted, amperes				
31,000	40,300	28,400	29,400	41,300
Restored volts				
4,030	3,800	4,000	4,150	3,920

Table III. Extended Series of Interrupting Tests on a Single Pole of a 5,000-Volt 250,000-Kva Magnetic "De-ion" Breaker

Test Number	Test Voltage	RMS Amp. Interrupted (Thousands)	Arcing Time Cycles	Equivalent 3-φ Mva
1	4,000	36.2	1/4	250
2	4,300	41.3	1/4−	308
3*	4,300	31.0	1/4	231
4	4,300	32.6	1/4−	243
5	4,300	29.0	1/4	216
6	4,300	33.6	1/4	250
7	4,300	37.2	1/4	277
8	4,300	38.8	1/4	290
9	4,300	33.1	1/4−	247
10	4,300	26.9	1/4	200
11	4,300	24.8	1/4	185
12	4,300	25.8	1/4−	194
13	4,300	23.3	1/4+	174
14	4,300	31.0	1/4	231
15	4,300	25.8	1/4	192
16	4,300	41.3	1/4+	308
17	4,300	33.6	1/4	250
18	4,300	40.3	1/4−	301
19	4,300	31.0	1/4−	231
20*	4,300	40.3	1/4	301
21	4,300	28.4	.1 −	212
22	4,300	28.4	.1	212
23	4,300	24.3	1/4	181
24	4,300	30.0	1/4−	224
25	4,300	36.2	1/4−	270
26	4,300	39.8	.1 −	295
27	4,300	29.5	1/4	220
28	4,300	37.2	1/4−	277
29*	4,300	28.4	1/4+	212
30	4,300	41.3	1/4−	308
31*	4,300	29.4	1/4	219
32	4,300	31.0	.1−	231
33	4,300	28.4	1/4	212
34*	4,300	41.3	1/4	308

*Oscillograms of these tests are shown in figure 9.



Current interrupted, amperes	
40,000	40,000
Restored volts	
4,020	4,020

Figure 10. Two consecutive high-current interruptions obtained with a 5-kv 250,000-kva magnetic "De-ion" breaker

ing dielectric strength in a previously high conducting region has been successfully applied to an air circuit breaker. Extended series of interrupting tests with currents as high as 40,000 amperes and restored circuit voltages of 4,020 volts across a single pole indicate a conservative interrupting rating of 250,000 kva. The magnetic "De-ion" air circuit breaker is suitable for severe repetitious duty, and also meets the requirements of modern metal-clad switchgear.

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Magnetic Fields in Watt-Hour Meters

Effects of Wave Form on the Registration of Single-Phase Watt-Hour Meters

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Synopsis: The growing use of electrical equipment which causes distortion in the supply voltage and current has caused increased concern regarding the performance of watt-hour meters used to meter the energy required by such equipment. The watt-hour meter is designed and adjusted, in practice, to operate on practically distortionless current and voltage.

An analysis of the factors involved and an experimental study of meter registration under definitely controlled conditions show that watt-hour meters should perform satisfactorily unless the degree of distortion is large. These controlled conditions included wide variations in the distortion of potential and current both individually and together. The characteristics of meters of recent design, of all the major manufacturers, were studied experimentally.

Introduction

THIS study of the effects of variation in wave form on the registration of a watt-hour meter is a part of a general study of the magnetic conditions which exist in such meters during their operation. Data which are presented for illustration of these effects are to be considered more qualitatively than quantitatively since they apply directly to particular types of meters of recent design. The order of magnitude of the effects of variations in wave form can be inferred in any case except perhaps for meters of very early design.

Single-phase meters only are considered here. The influence of the interaction of the several elements of polyphase meters is to complicate relationships introduced by a variation in wave form and depends upon the position of the elements relative to each other. Since the general effect of harmonics is found to be small, the relatively small influence of one element on another in a multidisk meter should give rise to effects of but minor importance so far as they are caused by harmonics.

Because of the necessary differences between the designs of elements of multidisk and single-disk polyphase meters, the effects of wave-form variations on the performance of single-disk meters are being given separate study.

Meters of recent designs, although made by various manufacturers are much more nearly alike, fundamentally, in their magnetic circuits than those formerly manufactured. Many differences in detail are still present and although the net result is, in each case, a meter with satisfactory performance characteristics, variations may be noted in the performances of the meters when used in circuits where abnormal wave forms occur in voltage or current.

In addition to differences in the proportions of parts of the magnetic circuits of the meters, design details which influence the flux distribution and variation in a meter and consequently the performance characteristics under abnormal loads are the lagging circuit and the compensations for friction, temperature change, and overload. No attempt is made to evaluate separately the influence of each component part, their collective influence only being noted. Even with meters of the same design, differences among them which are not evident under normal conditions may become noticeable under abnormal conditions.

Discussion

The operation of a watt-hour meter depends upon the interaction of the fluxes produced by the component magnetomotive forces of the potential and current elements and the disk currents produced by the changing of those fluxes. The changes in these fluxes may be in either magnitude or position or both. The distribution of these fluxes in the meter and their variations in magnitude with time are important factors in the determination of the disk torque upon which the meter registration depends. Differences in both the space distribution of the fluxes with time for the various meters are determined to a large degree by the differences in the details in the designs of the meters. Although the details of element design have some influence, the time variation of the flux is determined largely by the external conditions in the circuit. The design of the magnetic circuit, with associated electrical circuits, practically determines the space distribution of the flux. Because of the variable timing of the magnetomotive forces of the potential and current elements the space distribution of their resultant flux is variable and hence is a function of external conditions as well as the magnetic design. In a like manner, the time variation of the resultant flux depends upon the variations in magnetic reluctance introduced by the magnetic design as well as the magnetomotive force variation dictated by external conditions. The materials of construction and their physical properties will have marked influences on the flux and hence on the characteristics of the meter.

It is the purpose, here, to discuss the effects of variations in the wave form of current and voltage, as fixed externally, on the registration of watt-hour meters.

Generally, the net conditions existing in and around any circuit where currents and voltage are nonsinusoidal can be considered to depend upon all components, fundamental and harmonics, present. This dependence may be difficult to determine unless linear relations exist. However, in most instances in power circuits, if harmonics are present to an important degree it is because of nonlinear response of iron in magnetic circuits to magnetization. In such cases the third and fifth harmonics are usually most prominent and except in instances of very high magnetic densities are the only ones of importance. Frequently only the third harmonic is sufficiently large to have much influence. For this reason, an experimental study of the effects of one major harmonic (the third) should give an understanding of the effects to be expected in practical cases.

In any case, net meter-disk torque should be produced only when voltage and current of the same frequency are used because in such cases only is there a net transfer of energy. This applies to harmonic components as well as to the fundamental. Experimentally it has been found that this is not true in all cases with practical meters. Net torque is produced even though voltages and currents of different frequencies are used. However, a distinction must be made between potentials and currents and the meter fluxes that result from them. The presence of iron in the magnetic circuits of the meters with its nonlinear response

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to magnetizing forces will give rise to time variations in the fluxes of harmonics which are not present in the magnetizing forces. These harmonics may give rise to torque components which with reference to the torque produced by the fundamentals may be positive or negative. Figures 2–5 are reproductions of oscillograms showing the presence of such harmonics in the variation of the air-gap flux in a representative meter of recent design with only fundamental potential and current variations.

In certain single-phase watt-hour meters the cores of the current and potential elements are placed as shown in figure 1 relative to the disk. The points indicated along a center line of these cores designate positions at which the rates of variation of flux density are shown in figures 2, 3, 4, and 5. These rates of variation are for conditions specified and correspond to actual conditions of operation with sine waves of potential and current.

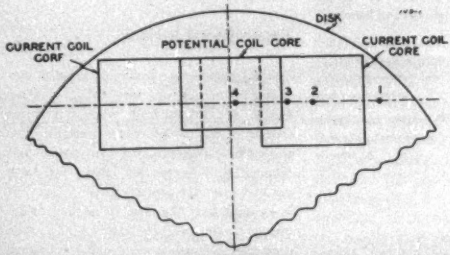

Figure 1. Plan—magnetic core of meter showing survey points

It will be noted that with sinusoidal potential impressed alone (figure 2), that the variations at all points approximate the sinusoidal. A careful analysis of these variations, however, shows that several harmonic components of small magnitude are present. The magnitudes at the various points differ widely. These conditions are to be expected since the flux linkages with the potential coil windings must vary in such a manner as to produce an induced voltage differing from the (sinusoidal) impressed voltage by only the resistance drop. This, with an iron core, requires that the induced voltage (and hence variation of flux) must contain harmonic components because of the harmonic content of the exciting current. These flux harmonics are of small magnitude relative to the fundamental as the curves of figure 2 indicate. The variations in amplitudes among the points are a result of the distribution of core material.

For the condition of the current coil alone, excited by sinusoidal currents (figure 3), the rates of variation of flux density at the various points are definitely nonsinusoidal. The nonlinear response of the iron to magnetizing force introduces harmonics of considerable magnitude. The influence of core distribution is evident.

With normal excitation for both potential and current elements, the resultant flux variation is not a superposition of those produced by each element acting independently. Portions of the magnetic circuit are influenced by both windings and having a nonlinear response, as stated before, will have resultant magnetic conditions which are not proportional to the component magnetizing forces. The conditions at the various points used to illustrate this are shown for two power factors in figures 4 and 5. In these cases the time relationship between the variations in flux density at the different points is not indicated in these figures.

Because of the difference in timing of the magnetomotive forces of the potential and current elements and the distribution of magnetic core material, the distribution of the resulting flux is not fixed. The variation includes both magnitude and position. Because of this shifting position and magnitude, a variable torque, tending to drive the disk, is produced. This variable torque can be considered as the resultant of many component torques, some positive, some negative. These components can be considered as produced by the fundamentals and harmonics in the space distribution and time variation of the air-gap flux as in any motor.

Although the net instantaneous torque in the case of sinusoidal potential and current is not uniform the single-phase watt-hour meter can be adjusted to give satisfactory registration characteristics. With external circuit conditions such that nonsinusoidal voltage or current or both exist, the proportions of the component

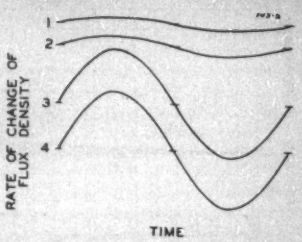

Figure 2. Cyclic rate of change of flux density for rated sinusoidal potential excitation only

Numbers on curves identify the survey points of figure 1

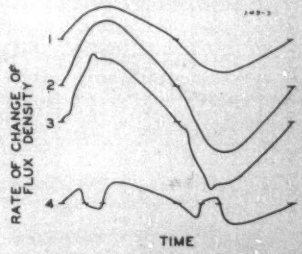

Figure 3. Cyclic rate of change of flux density for rated sinusoidal current excitation only

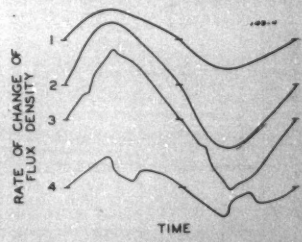

Figure 4. Cyclic rate of change of flux density for both rated sinusoidal potential and rated current excitation at unity power factor

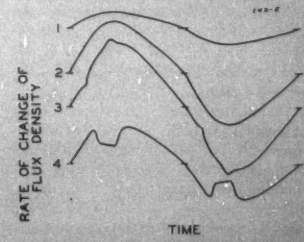

Figure 5. Cyclic rate of change of flux density for both rated sinusoidal potential and rated current excitation at 80 per cent power-factor lag

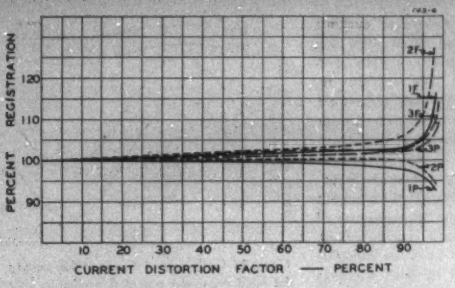

Figure 6. Per cent registration as a function of current-distortion factor for a resistance load with rated sinusoidal potential and rated current (effective value)

Numbers on curves identify manufacturer of meters

Curves *F*—Flat-topped current waves

Curves *P*—Peaked current waves

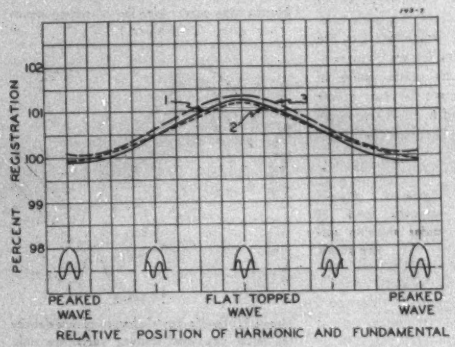

Figure 7. Per cent registration as a function of relative time position of fundamental and harmonic

Sinusoidal potential, constant power, current-distortion factor of 40 per cent

Numbers on curves identify manufacturer of meters

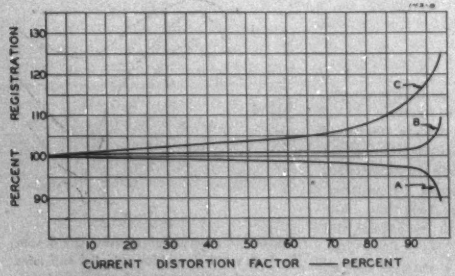

Figure 8. Per cent registration as a function of current-distortion factor for sinusoidal potential and peaked current waves

Curves for meter number 1 at rated current

Curve *A*—Fundamental current in phase with fundamental voltage

Curve *B*—Fundamental current lags fundamental voltage by 37 degrees

Curve *C*—Fundamental current lags fundamental voltage by 60 degrees

torques caused by harmonics will differ from that for which the meter is adjusted and the registration characteristics of the meter altered. The curves of figure 6 show the effects of nonsinusoidal waves of current.

In practical cases, either the voltage or current or both may be essentially sinusoidal functions of time, or either or both may differ sufficiently from the sinusoidal to warrant study. The probable combinations of conditions which may be encountered in practice are (1) both sinusoidal, (2) potential sinusoidal with current nonsinusoidal, (3) both nonsinusoidal. Since the effects of nonsinusoidal conditions are under consideration the base for comparison is taken as the combination (1) namely, the current and potential both sinusoidal.

For cases of nonsinusoidal conditions, varying degrees of distortion as well as various time relationships between harmonic components and the fundamental are considered. For purposes of establishing a measurable effect the distortion was limited to that caused by the presence of a third harmonic. Similar effects should be noted for other harmonics. It will be realized that as the number of harmonic components increases, the number of possible time relationships between the components increases beyond possible experimental study.

The term "distortion factor" is defined as "the ratio of the effective value of the residue after the elimination of the fundamental to the effective value of the original wave." (A.S.A. C-42-1932 section 10.95.430.)

For the case of nonsinusoidal variation of both potential and current an unlimited number of combinations are possible depending upon circuit conditions. Several examples are given, the conditions being noted with the curves showing experimental results.

Experimental Results

The curves of figure 6 show meter registration as a function of the distortion factor of the current wave for three makes of meters of recent design. The potential variation for all cases was sinusoidal. Curves are given for both peaked and flat-topped wave forms. It is evident that the disk speed should decrease as the per cent current distortion increases because under such conditions, the average power decreases. However, for all cases, the meter registration was computed as the ratio of actual disk speed to the disk speed for sinusoidal potential and current conditions giving the same average power. Although the large registration error, indicated on the curves, exists at large per cent values of current distortion, loads of this character are seldom experienced in practice.

For large values of distortion factor, the registrations of the meters with peaked currents differ greatly from those for flat-topped currents. These two wave forms can be considered as limiting cases of the time relationship between the fundamental and third harmonic components of current. For intermediate relationships of the components, intermediate values of the effects would be expected. Figure 7 shows the influence of the time relationship of the components for a constant-load and a constant-current distortion factor of 40 per cent.

Curves are shown for the three makes of meters as in figure 6. It can be noted that for all meters, flat-topped current waves gave the greatest meter registra-

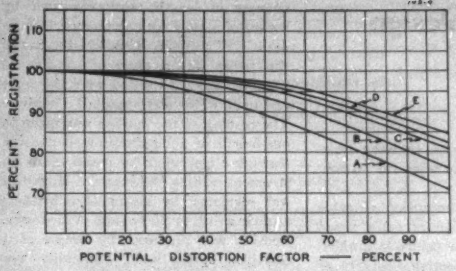

Figure 9. Per cent registration as a function of potential distortion factor for nonsinusoidal potential and current waves

Curves for meter number 1 at several resistance loads for peaked wave form

Curve *A*—20 per cent load
Curve *B*—50 per cent load
Curve *C*—100 per cent load
Curve *D*—200 per cent load
Curve *E*—300 per cent load

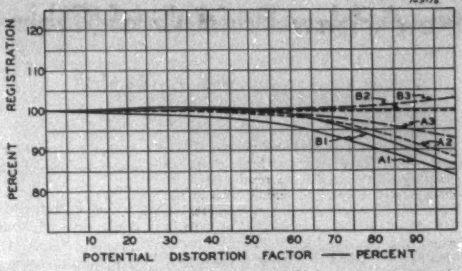

Figure 10. Per cent registration as a function of potential distortion factor for nonsinusoidal potential and current waves

Peaked wave form, two inductive loads
Fundamental current lags fundamental voltage by 37 degrees
Numbers on curves identify manufacturer of meters
Curves *A*— 25 per cent load
Curves *B*—150 per cent load

tion with a sine wave of potential and that all meters showed about the same performance.

The performance of the meters differed widely for large values of current distortion factor, although all meters were adjusted to give correct registration with zero-distortion factor. Harmonic components in the currents in the current-element windings, through magnetic coupling between those windings and circuits in the details of design, give rise to harmonic currents in those circuits not in exact phase opposition to those in the current coils. These harmonic components may produce torques which have an appreciable magnitude relative to the fundamental torque. It was noted during the tests that 100 per cent current-distortion factor with the potential element unexcited some meters crept backward rapidly, some forward rapidly, and some did not creep. With the potential coil short-circuited or excited, disk movement was reduced in magnitude. At large values of distortion factor the summation of the torques due to harmonics became an important factor in the total torque.

All test meters responded similarly to variations in the phase angle between the fundamental components of potential and current. Figure 8 shows meter registration as a function of distortion factor for peaked waves of current and for three values of fundamental phase angle. The voltage and current were rated values.

For conditions of distortion in both potential and current waves, an unlimited number of combinations are possible. If the load is noninductive the distortion of both the waves should be the same. Under these conditions the time variations of the magnetomotive forces caused by both the potential and current circuits of the meter contain corresponding harmonic components. It should be noted, however, that the presence of corresponding harmonic components in the magnetomotive forces does not imply the presence of harmonic components in the fluxes having the same relative relationships as those of the magnetomotive forces.

Because of the higher frequency, the potential flux per volt for a harmonic is less than that for a fundamental. The variations in the air-gap flux will then be the resultant of components of different relative magnitudes than the respective component voltages. The effects of such conditions on the registration of a typical meter at various per cent loads and for peaked waves are shown in figure 9. Experimental results, using flat-topped waves, differed but slightly from those for peaked waves. In no case was this difference more than one-half per cent. With resistance loading, a reversal or change of any component in the voltage was accompanied by a corresponding change in the current component of that frequency. The net result of the change on the registration of the meters was of no practical magnitude. The flux density at which modern meter cores operate is low enough to make the effects of changing the maximum flux density (caused by change in wave form) small.

When the load circuit is inductive, the distortion factors of potential and current differ. One example of such loading gave results shown in figure 10. In this case, load resistance and inductance were of such values as to produce a fundamental phase displacement of approximately 37 degrees (0.8 power factor) the fundamental current lagging the voltage. Peaked waves of potential were used. The load power was constant.

Conclusions

1. Meter registration errors, as the result of wave distortion, for properly adjusted meters, usually will not exceed the limits of permissible calibration error unless the current-distortion factor is greater than 30 per cent.

2. Indicating instruments are recommended for use in the testing of watt-hour meters when the distortion factor of the current exceeds 50 per cent.

3. No definite statement can be made regarding the effects of distortion on meter registration if the potential distortion is the result of impedance drops caused by distorted currents since the time relationships of the harmonic components depend on circuit conditions.

4. Because of the differences in the space and time variations of the fluxes which would be produced by fundamental and harmonic components of potential, current or both, the net registration of a meter is not the summation of the registrations that the several harmonic components of potential and current would produce, each acting alone.

5. As a result of observations made during the tests it is believed that minor differences in the adjustments required to give satisfactory registration by meters of the same model may cause noticeable differences in the effect of wave distortion on the characteristics of the meters.

6. In the majority of meter applications where minor distortion of current or potential exists the watt-hour meter of recent design measures the energy satisfactorily if adjusted within the limits of commercial accuracy under customary testing conditions.

A New Principle of Cable Design

WM. A. DEL MAR
FELLOW AIEE

Synopsis: Study of cable behavior on load-cycle tests led to the conclusion that instability of the insulation results from its deformation, leaving ionizable voids in the inner layers, where deterioration starts.

This led to the conception of a cable in which the inner and outer layers of paper would have different moduli of elasticity, the outer papers having the higher modulus so that during the cooling period of a load cycle, the outer papers would compress the inner ones and so reduce or eliminate voids therein.

The tension of application of the tapes is the same for all layers and does not depart from ordinary practice.

It was found that cables made on this principle maintained a remarkable stability of power factor under load-cycle conditions.

Finally, a study of cable impregnants showed that an essential characteristic is stability under electrical discharges. An impregnant was developed consisting of a paraffin base oil with a definite proportion of a new synthetic derivative of wood rosin, which possesses this characteristic in a marked degree. This, used in combination with the above-described structure gives the maximum stability we have been able to attain.

IT HAS been the general belief that oil-filled paper cables differ from solid-type paper cables in that the former have a perfect radial and longitudinal flow and ebb of oil throughout the insulation during heat cycles whereas in the latter, the oil flows but does not ebb, perfectly, leaving ionizable voids in the depth of the insulation.

It is undoubtedly true that, in the oil-filled cable, the oil flow is reversible but our researches show that in the solid-type cable, there is little flow of oil out of the insulation at ordinary operating temperatures and, therefore, substantially no trouble to be expected from its imperfect ebb. The view is expressed herein that the real difference between an oil-filled cable and one of solid type is that, in the former, the oil is of such low viscosity that it can flow out and back again under pressure too small to deform the paper permanently, whereas in solid-type cables, the oil viscosity is so great that very high pressures are created by the expanding oil which tend to stretch the paper permanently, creating gaps between tapes which become vacuous when the oil contracts.

This is a useful conception of cable operation and a design of cable based upon it is described, the principle of which is to improve the effective elasticity of the mass of paper by using successive layers of increasing modulus of elasticity, so that each layer will be held in compression by circumjacent layers of greater modulus.

By this means the insulation of solid-type cable acquires some measure of the reversibility characteristic of oil-filled and pressure cables but without adding in any way to the dimensions or complications of the cable or its accessories.

The construction now used consists merely in the use of two layers of paper, the inner comprising three-fourths of the thickness, and the outer, one-fourth of the thickness of the insulation, the paper of the outer layer having a modulus of elasticity 15 per cent to 20 per cent greater than that of the inner layers.

Relative Imperviousness of Impregnated Paper to Viscous Oil Flow

Tests were made to establish the critical viscosity at which oil can move through insulation without exerting enough pressure to put undue stress on the paper.

Typical test results are shown in figure 1. It will be noted that with viscosities above 1,000 to 2,000 seconds there is but little pressure transmission through the insulation. Furthermore, in an operating cable, the oil temperature in the middle of the insulation will be considerably less than at the conductor, so that compound does not flow until the oil at the conductor surface has attained a considerably higher temperature than would be suggested by the data on figure 1.

Elastic Properties of Cable Paper

A study of the elastic properties of impregnated-paper cable was undertaken in order to better appreciate the stresses and strains arising from cyclical loading of cables. A cabinet was constructed capable of holding in vertical suspension a strip of paper one meter in length, changes in length being measured by means of a steel scale graduated in hundredths of an inch. Glued to the end of the paper was a piece of transparent celluloid which extended over the scale and upon which was scratched a hairline. The reading of the hairline was made to one-fourth of a hundredth-inch division through a glass door by means of an instrument-reading telescope. Humidity was regulated by means of anhydrous acids in a dish at the bottom of the tower. Tension was produced by means of a Chatillon spring scale. Humidity was measured by means of a calibrated Taylor humidiguide. The appearance of the setup is shown by figure 2.

It was found that impregnated-cable paper has peculiar physical properties, which would be likely to influence its behavior in a cable. The stress-strain characteristic of a typical cable paper is shown by figure 3. Different papers, however, have different slopes of curve, corresponding to different moduli. Although the graph is a straight line up to about 5,000 pounds per square inch, the paper is not perfectly elastic, within that range, but has a permanent set after each cycle of stretching, the amount of set rising with the tension. The relation between elongation and permanent set was found to be of the form shown by figure 4.

Armed with these data, the next step was to calculate the paper tensions that would result from oil expansion. This was started with the generally accepted idea that this expansion would cause the tape to stretch, thereby separating the layer sufficiently to permit the expanding oil to flow freely outward toward the sheath. The accepted idea was that in cooling, the elasticity of the paper would cause it to close in upon the contracting oil, even to the extent of the outer layers cutting off some of the oil before it could return to the interior of the cable.

It was found, on the contrary, that the paper did not stretch sufficiently to create the necessary oil passages between layers, but that, with the calculated stresses, the permanent set was sufficient to leave voids in cooling.

The obvious step to be taken to improve the quality of cable was to use a truly elastic paper, but we could not find a paper which showed true elasticity when impregnated. All papers tested showed more or less permanent set.

It was noted, however, that different papers had different moduli of elasticity and the idea presented itself of placing layers of paper of high modulus over layers of low modulus so that as the inner papers were stretched by the expanding

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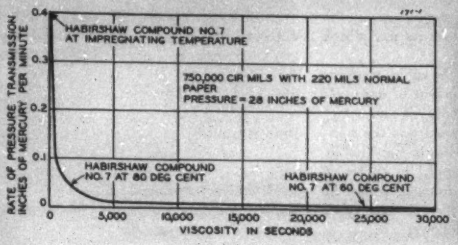

Figure 1. Relative imperviousness of impregnated-paper cable to viscous oil under pressure

Viscosities above 3,500 seconds which could not be measured on the Saybolt universal viscosimeter were measured by rate of penetration through single sheets calibrating the sheets with an oil of known viscosity

Figure 2. Test chamber for modulus determination

oil, they would meet resistance by the outer layers and in cooling, the pressure exerted by these outer layers would help to restore the inner layers to their original condition.

In order to test the correctness of this theory, cables were made with two grades of paper, the inner layers being made with the normal paper and the outer layers with paper having about 20 per cent greater modulus of elasticity. These cables were tested in comparison with cables of normal construction by means of load-cycle life tests.

Accelerated Aging Tests

The best available data on the correlation of accelerated aging with natural aging were those of the Commonwealth Edison Company published by D. W. Roper, AIEE TRANSACTIONS, volume 52, 1933, page 1028 and by Halperin and Betzer, AIEE TRANSACTIONS, volume 55, 1936, page 1074.

In order to ensure that our tests should be equally correlated with service conditions we decided to make our tests at the same maximum stress, as in the Halperin-Betzer tests, namely 208 volts per mil and at a conductor temperature five degrees centigrade over the normal operating temperature. When meter corrections were taken into account, our actual maximum stress was 203 volts per mil. The cable type selected for test was a 4/0 AWG, 19 strand, single-conductor cable with 220 mils of insulation and 63 mils lead sheath.

Heating current was maintained for eight hours per day, five days per week. Voltage was maintained the full 24 hours and over weekends, except for intervals while measurements were being made.

Roper reported that tests made under these conditions gave failure of similar nature to those occurring in service and that it would be unnecessary to carry the tests to failure as the rising power factor, ionization and hot-spot temperature would differentiate between cables of different qualities in the course of from two to seven weeks, i.e., 10 to 35 load cycles.

Our preliminary work showed that this generalization was also applicable to our tests.

Poorly impregnated cables, i.e., cables drained of part of their oil, were eliminated in two weeks, i.e., 10 or 12 load cycles.

Questionable cables were eliminated in four weeks, i.e., 20 load cycles.

Good cables, as then made, lasted at least five or six weeks, i.e., 25 to 30 load cycles.

Roper found that whereas tests made at $2^1/_2$ times operating voltage, corresponding to a maximum stress of 208 volts per mil were indicative of service life, those made at three times operating voltage, corresponding to a maximum stress of 250 volts per mil, had no such significance but, on the contrary, were quite erratic.

The suggestion that tests be discontinued before failure, was a fruitful one as it not only enabled more tests to be made in a given time, but also permitted examination of the cable where failure seemed imminent and before destruction of the evidence occurred. The tapes from a typical arrested failure on a cable of ordinary type is shown in figure 5.

As the tests were to be discontinued when the cables showed signs of instability, it was necessary to establish arbitrary limits indicative of this condition.

The Commonwealth Edison limits and those we adopted were as follows:

	Commonwealth Edison Company	Habirshaw
Power factor at 85 degrees centigrade		2.00
Rise of power factor at high temperature of cycle (per cent)	0.75	
Rise of ionization (per cent)	0.50	0.50
Hot-spot temperature rise (degrees centigrade)	8	8

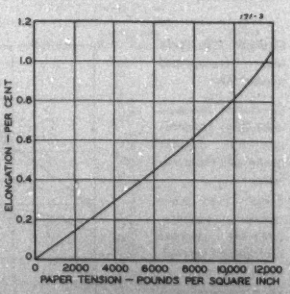

Figure 3. Elongation of normal cable paper impregnated

Each test was made on a set of four cables impregnated at the same time, each 15 feet long and equipped with pressure-tight terminals. The initial power factors on these four supposedly identical cables were nearly equal but not identical. As, however, they tended to equalize after a few load cycles, it seemed fairer to set the limit at a certain final power factor rather than a definite rise from the start. A value of two per cent was chosen as giving results close to those of the Commonwealth Edison Company.

The first load-cycle tests were made with two sets of cables, one made up with 160 mils of normal or type *N* paper surrounded by 60 mils of high modulus or type *S* paper, a construction referred to for convenience as "Titebilt," the other

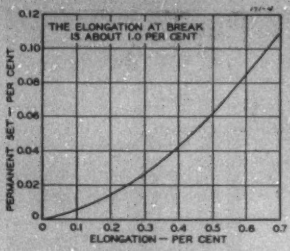

Figure 4. Permanent set of normal cable paper impregnated

made with the same total thickness of paper as ordinarily used, i.e., 50 mils of paper, selected for high density, covered with 170 mils of type *N* paper. The average number of cycles required to reach the limits set were as follows:

Set Number 1

Construction	Power Factor	Ionization	Hot Spot	Breakdown
Ordinary	25	25	22	25
Titebilt	60	82	64	82

Another series of tests was made, adding, however, a set of cables made entirely of type *S* paper. It was expected that if the elasticity theory were correct, the cables made of this kind of paper should be inferior to the Titebilt cable. This was confirmed by the following results:

Construction	Average Number of Load Cycles to Reach Power-Factor Limit Set Number 2
Ordinary construction	30
220 mils of type *S* paper	42
Titebilt	69

The progress of power-factor rise in the Titebilt and ordinary cables for set number 2 is shown in figure 6. It will be noted, that the Titebilt cable shows a smoothly rising curve which contrasts remarkably with the erratic curve of the ordinary cable. The power-factor curve of the Titebilt cable did not show any final upturn until two or three cycles before failure.

The above tests were confirmed by two more sets of tests as follows:

Construction	Load Cycles to Reach Power-Factor Limit Set Number 3	Set Number 4
Ordinary	27	29
Titebilt	72	75+

Set number 4 was stopped when the Titebilt cable had shown its undoubted superiority.

After all these tests the cables were examined and a large amount of data collected. After the stability of power factor, the first feature noted was the complete absence of dendrites in the Titebilt cables. Cable wax formed in cables of both types, but less frequently and in smaller amounts in the Titebilt type. The exact data are as follows:

Construction	Cables With Dendrites (Per Cent)	Cables With Wax (Per Cent)
Ordinary	36	57
Titebilt	0	25

No gas was found in the tape-edge channels of the Titebilt cables whereas many of the other cables showed varying amounts of gas.

The average ionization of cables of the ordinary type was 0.069 per cent at the end of the life tests whereas that of Titebilt cables was 0.058 per cent in spite of the fact that the latter lasted more than twice as many cycles on life test.

Four lengths of Titebilt cable constituting set number 5 were tested on load cycle at 243 volts per mil, maximum stress which, as indicated above, is too high to yield results comparable with operating conditions. Two of these developed slight dendrites in the *outer* half of the insulation. The dendrites in ordinary cable always appeared in the inner half of the insulation. This shows that the inner part of the insulation, which carries the highest electrical stress at operating voltages, remains tighter in the Titebilt cable, affording an interesting proof of the Titebilt principle. The same peculiarity has since been noted in Titebilt cables tested to breakdown in accordance with AEIC specifications.

In addition to these five recorded sets of tests, there were numerous preliminary tests and tests to obtain specific design data, all of which substantiated the Titebilt design.

Belted Cable

So far, all the discussion has related to single-conductor cable, although obviously, the Titebilt idea is equally applicable to multiple-conductor shielded cable. The principle is not so easily applied to the belted cables, but considerable benefit has been found to result

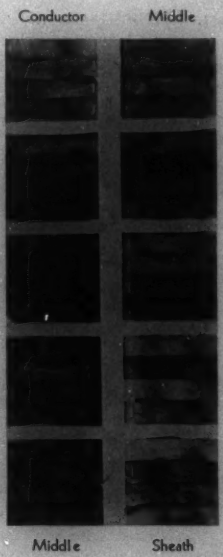

Figure 5. Arrested failure of ordinary cable

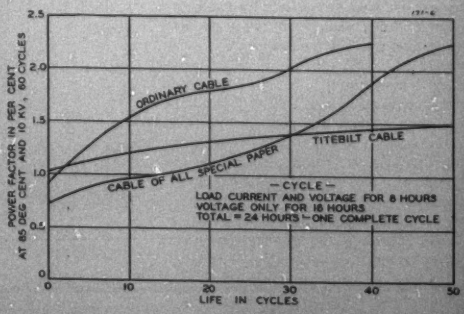

Figure 6. Life-cycle tests (compound number 7)

Conductor maximum operating temperature = 85 degrees centigrade (approximate)

Sheath maximum operating temperature = 60 degrees centigrade (approximate)

Room temperature = 25 degrees centigrade (approximate)

Figure 7. Three-phase load-cycle test equipment

from using the Titebilt composite construction for the conductor insulation.

For instance, one such test was on cable having an AEIC rating of 12,000 volts. It was tested at 24,000 volts; i.e., at twice rated voltage, but the copper temperature was brought up to 85 degrees centigrade. After 30 cycles the Titebilt cable power factor at 85 degrees centigrade rose from 1.01 to 1.06 per cent, whereas that of the old type cable rose from 1.04 to 1.22 per cent. The layout for this test is shown in figure 7.

In general, these tests showed that Titebilt belted cable was consistently superior to the old type cable but by a smaller margin than in the case of the single-conductor and shielded cables.

Compound Number 8

The tests recorded above were all made with compound number 7, a preponderantly paraffin base oil with 15 per cent wood rosin. The following tests were made with cables of the Titebilt construction, using compound number 8 consisting of the same oil with ten per cent of a synthetic derivative of rosin, namely hydrogenated wood rosin.

The type of test on single-conductor cables, described above, proved to be quite inadequate for cables made in this way. It will be remembered that while ordinary cables attained the two per cent power factor (85 degrees centigrade) limit in from 25 to 30 load cycles and the original Titebilt cables in from 60 to 75 load cycles, there was no indication that Titebilt cable with compound number 8 would attain the limit within two or three times that number. In fact, the test seemed to have no effect on the power factor of the cable.

The compound itself, tested, in a new type of bombardment cell, shown in figure 8, gave remarkable results. In preparing a sample of oil for test, the assembled discharge cell is placed on a water bath held at 100 degrees centigrade, and is then evacuated to an absolute mercury pressure of 0.1 millimeter, the residual being air. A sample of oil weighing 25 grams is poured into the funnel of the oil inlet, from which it is slowly drawn into the discharge chamber and degassed. After degassing the apparatus is allowed to stand for one hour at room temperature. At this time, a potential of 9,000 volts, 60 cycles, is applied to the test cell from a gas-sign transformer, and continued for 1,000 minutes. The relative oil stabilities are determined by change of power factor as measured in a Davidson power-factor cell. Whereas in this cell compound number 7 ended the test with a power factor of 4.0 per cent at 85 degrees centigrade, compound number 8 underwent the same ordeal and ended with a power factor of 0.4 per cent. This compound mixes with joint oils, in all proportions, without appreciable rise of power factor.

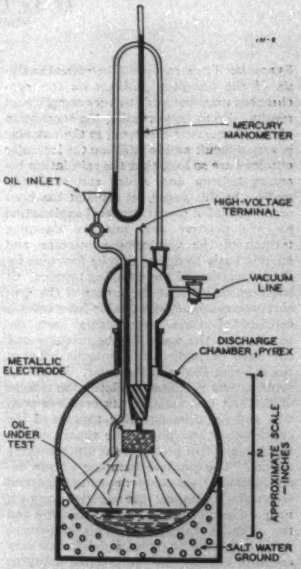

Figure 8. Merrell discharge cell for oil-stability tests

At this stage of our work Mr. Halperin called our attention to a new type of load-cycle test which he had developed that was calculated to be more destructive than the old and we decided to test a three-conductor shielded cable of the new design. This test procedure is described in his 1939 AIEE paper. Like the earlier one, it uses heating and cooling periods with voltage but instead of a single upper temperature of 85 degrees centigrade, it includes cycles at conductor temperatures of 60, 80, 100, and 115 degrees centigrade at twice operating voltage, corresponding to an average stress of 114 volts per mil and a maximum stress estimated at about 195 volts per mil, i.e., substantially the same as in the earlier tests.

The main criteria of stability are the change in the ionization factor at room temperature and in the power factor at 24 kv and 60 degrees centigrade, so that a cycle at that temperature was made after each of the groups of cycles at higher temperatures.

Table I. Load-Cycle Test of Titebilt Cable

Three-Conductor, 500,000-Circular-Mil, Type *H*, 122 Mils of Insulation (Rated at 7,000 Volts), 117 Mils of Lead

Week*	Load Cycles: Number of Cycles	Load Cycles: Maximum Temperature (Degrees Centigrade)	Hours: Heating	Hours: Cooling	Power Factor at 60 Degrees Centigrade (Per Cent)	Ionization Per Cent at Room Temperature
Standard test						
Start					0.39	0.01
1	2	60	7	17	0.39	0.04
	3	80	7	17		
2	1	60	7	17	0.39	0.00
	4	100	7	17		
3	2	60	7	17	0.40	0.01
	3	115	7	17		
4	5	60	7	17	0.39	0.00
Supplemental test						
5	1	60	48	9		
	1	85	15	9		
	2	100	15	9		
	1	115	15	9		
		60	15	48	0.40	0.00

*Saturdays and Sundays, after each week of test, the cables carried 24 kv but no load current.

Ionizations which were reported as having small negative values are entered as zero.

Positive and Negative Damping in Synchronous Machines

M. M. LIWSCHITZ
MEMBER AIEE

Synopsis: The straight mathematical analysis of the damping problem on the synchronous machine leads to very complicated results. From these results, the conception of the phenomena occurring in the machine is very difficult and in addition the formulas obtained are so long that the calculation becomes tedious and errors can easily be made. In this paper, an attempt has been made to find a simple physical explanation for the positive and negative damping torques of the synchronous machine and on this basis to derive simpler formulas for the calculation of the damping torques. It has been found that the torque of the synchronous machine, as a double-fed machine, consists of three components, two dependent on the speed of the machine and the third dependent on the angle between the rotating field and the rotor. When the synchronous machine oscillates, the change of the first two components produces positive and negative damping torques of the synchronous machine. The change of the third component produces the synchronizing torque. The positive damping torque depends mainly on the primary voltage and secondary resistance; the negative damping torque depends mainly on the excitation and the primary resistance. This knowledge made it possible to derive a simple and very accurate formula for the positive damping torque as well as a simple approximate formula for negative damping torque. On the basis of these formulas, the influence of the two axes of the machine on the damping can be easily found. A comparison between the results obtained by using the simple formulas and the long accurate formulas as well as a comparison between calculation and test on a small machine have been carried through.

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1: For all numbered references, see list at end of paper.

I. Simple Equations for Determining the Damping and Synchronizing Torque

FOR the purpose mentioned, a symmetrical machine will be considered first, both parts of which have polyphase windings carrying currents of different frequencies f_1 and f_2. The frequency f_1 as well as the corresponding voltage E_{L1} are assumed to be constant. All quantities and constants involved will be reduced to terms of this side of the machine. As shown in appendix the torque of such a machine is equal to (all values in per unit notation)

$$T = [e_1^2 r_1 - e_2^2 r_1 + e_1 e_2 \sqrt{l_1^2 + m_1^2} \times \sin(\delta_0 + \alpha)] \frac{1}{l^2 + m^2} \quad (1)$$

l_1, m_1, l, and m are functions of the slip $s = f_2/f_1$.

Thus the torque consists of three components. The first two components are dependent on the speed of the machine, the third component is dependent on the speed of the machine as well as on the angle between the both line voltages e_1 and e_2. The first component is the well-known torque of the normal induction machine.

The synchronous machine is a special case of the double-fed machine, with $f_2 = 0$ and $e_2 = I_2 x_2$.

The three components of the torque T (equation 1) will change their value when the double-fed machine oscillates. To the change of the first two components of the torque will correspond a damping torque, to the change of the third component will correspond a synchronizing torque.

Thus the damping torque consists of two components, one positive and the other negative. The positive component is proportional to the square of the primary voltage and is dependent on the secondary resistance; it is equal to zero, when the secondary resistance is equal to zero. The negative component is proportional to the square of the secondary

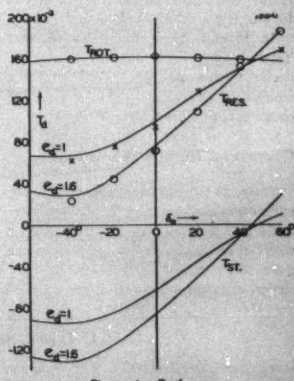

Figure 1. Both axes

A test of this kind on Titebilt cable with compound number 8 is described below.

Shielded Three-Conductor Cable

A cable of the following construction was made, having an AEIC rating of 7,000 volts and tested at 24,000 volts in accordance with procedure described above.

Three-conductor 500,000 circular mils
Insulation 122 mils { type N, 90 mils / type S, 30 mils
Impregnant, compound number 8
Shield, three-mil copper with intercalated paper
Fillers, paper
Binder, five-mil bronze
Lead, copper bearing, 117 mils
Length of test piece, 25 feet under lead
Position of ends during test, horizontal
Condition during test, pressure tight

The cycles of load are given in table I with the power factors at 60 degrees centigrade at the end of each week. It will be noted that the new Titebilt cable, showed substantially no change in either power factor or ionization. Two cables were subjected to the above test and a third one to the first four weeks only, with the same result. A 115-foot sample of the same cable was subjected, at Chicago, to the same type of test with practically the same results.

Similar tests are recorded by Halperin, AIEE TRANSACTIONS, volume 58, 1939, page 536, where it is shown that standard 12,000-volt (3/64 inch by 4/64 inch) belted cables made in 1937 and 1938 show power-factor increases of 19 to 300 per cent of the original values and ionization rises from substantially zero to 0.5 per cent, absolute values.

While Titebilt cable was developed along the line of scientific utilization of mechanical properties of paper, the disposition of the papers planned on that basis may, and probably does, lead to a better arrangement from other points of view, which I hope to express on some subsequent occasion.

voltage and is dependent on the primary resistance; it is equal to zero, when the primary resistance is equal to zero or when the secondary voltage (in terms of the synchronous machine, the excitation) is equal to zero. The positive component of the damping torque will be called rotor-damping while the negative component will be called stator-damping.

It is now possible to derive a simple formula for the rotor-damping of the synchronous machine (1 and 3). It is (for the symbol s. List of Symbols)

$$T_{rot.} = \frac{e^2}{Z}\left[\frac{r_{2d}/s_p}{Z_{2d}^2}\sin^2\delta_0 + \frac{r_{Dq}/s_p}{Z_{2q}^2}\cos^2\delta_0\right] \quad (2)$$

where

$$s_p = \frac{Z}{\omega} \qquad \tau_{1d} = \frac{x_1}{x_{ad}} \qquad \tau_{1q} = \frac{x_1}{x_{aq}} \quad (3)$$

$$x_{1d} = x_1 + (1+\tau_{1d})x_{2d} \qquad x_{1q} = x_1 + (1+\tau_{1q})x_{Dq} \quad (4)$$

$$Z_{2d}^2 = [(1+\tau_{1d})r_{2d}/s_p]^2 + x_{1d}^2$$
$$Z_{2q}^2 = [(1+\tau_{1q})r_{Dq}/s_p]^2 + x_{1q}^2 \quad (5)$$

The rotor damping of the asynchronous machine is determined directly by the slope of the speed-torque curve which is represented by the first component of the equation 1. The rotor damping of the synchronous machine is dependent on this slope at $s=0$ and in addition is modified by the angle δ_0 which determines the power of the synchronous machine.

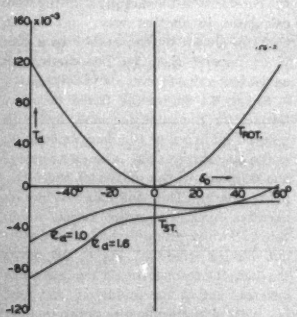

Figure 2. Direct axis

The result given by the equation 2 will be compared with that obtained by Doherty and Nickle in their "Synchronous Machines, Part III"[2] where r_1 is assumed to be equal to zero. The comparison will be made for a 48-pole machine of 2,500 kva, 6,000 volts, 50 cycles, but in order to make the negative damping more noticeable, it will be assumed that this machine has an abnormally high stator resistance, and that it operates on 1,000 volts, 8 cycles per second. Under these conditions, the constants are:

$r_1 = 0.20$	$r_{2d} = 0.022$
$x_1 = 0.116$	$x_{2d} = 0.301$
$x_{ad} = 0.855$	$r_{Dq} = 0.078$
$x_{aq} = 0.519$	$x_{Dq} = 0.08$

Further, it is assumed that $Z = 5.03$; i.e., $s_p = 0.10$.

The curve $T_{rot.}$ in the upper part of figure 1 was calculated by using the formula contained in said paper, the circles were calculated by using equation 2. The agreement is very satisfactory, as has been found on many other occasions.

Unfortunately, it is not possible to find a similarly simple and accurate formula for the stator (negative) damping. On the basis of the second term of the equation 1 and with support of calculations using the exact formulas it is possible, however, to derive an approximate formula that gives satisfactory results for the usual range of δ_0 ($\delta_0 = +35$ degrees to -35 degrees) and for excitations corresponding to $e_d = 1.0$ to 1.6.

When using the second term of the equation 1 it has to be considered that in the synchronous machine the voltage e_2 corresponds to the ohmic drop of the secondary current and that this current multiplied by the reactance of the armature reaction is equal to the electromotive force induced in the stator. Thus the main quantities of the second term of the equation 1 are involved. The influence of the angle δ_0 upon the stator damping is taken into account by two factors k_1 and k_2 based on the exact formulas. Thus, the approximate formula for the stator-damping is:

$$T_{st.} = -\frac{e_2}{Z}\frac{r_1}{\left(\frac{x_{ad}+x_{aq}}{2}\right)^2} \times \left[\left(\frac{e_d}{e}\right)^2\frac{(r_{2d}/s_p)^2}{Z_{2d}^2}k_1 + \frac{(r_{Dq}/s_p)^2}{Z_{2q}^2}k_2\right] \quad (6)$$

For a generator:

$$k_1 = 1 - \tan^2\delta_0 \qquad k_2 = 1 - \sin 2\delta_0$$

and for a motor:

$$k_1 = 1 + \tan^2\delta_0 \qquad k_2 = 1 - \sin\frac{\delta_0}{2}$$

The values of the resultant damping torque $T_{d\,res.} = T_{rot.} + T_{st.}$ given by the equations 2 and 6 will be compared with those obtained by Park[4] on the assumption $x_{ad} = x_{fd}$ and $x_{aDq} = x_{aq}$. As in the comparison with Doherty and Nickle, it is further assumed that there is only one winding in the direct axis.

In the figure 1 the curves $T_{res.}$ are the torques obtained by using Park, the crosses and circles are values calculated

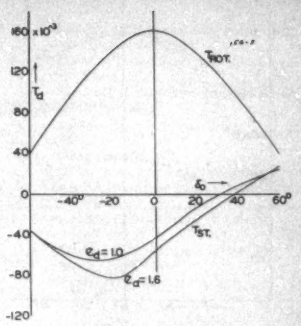

Figure 3. Quadrature axis

from the equations 2 and 6. The agreement is satisfactory. It should be remarked that the damping torques obtained by Nickle and Pierce[6] for the running as a *motor* at the heavier loads are about 30 per cent higher than those obtained by Park; i.e., in this range the method of Nickle and Pierce gives too small values for the negative damping.

In the bottom part of the figure 1 is shown separately the stator (negative) damping torque. The negative damping is much larger when the machine operates as a motor than when it operates as a generator. For the same (absolute) value of the angle δ_0 the resultant damping for the motor is much lower than for the generator. The negative damping torque increases with increasing excitation. This influence of the excitation is also larger for the motor than for the generator The rotor-damping of the synchronous machine is positive for any angle δ_0, while in the normal induction machine the rotor-damping can also be negative. In the normal range of δ_0 the stator-damping of the synchronous machine is always negative, however, at large *positive* values of δ_0 it can become positive.

The figures 2 and 3 show the rotor-damping as well as the stator-damping for both axes separately. For small values of δ_0 the negative-damping in the direct axis is greater than the positive damping, while in the quadrature axis the negative damping is at any angle δ_0 smaller than the positive damping.

The curve T_d of the figure 4 gives the comparison between the results obtained by Park and those obtained by using the equations 2 and 6 for the same machine as above, but at 50 cycles, $s_p = 0.027$ and a primary resistance 70 per cent higher than normal. The agreement between both methods of calculation is satisfac-

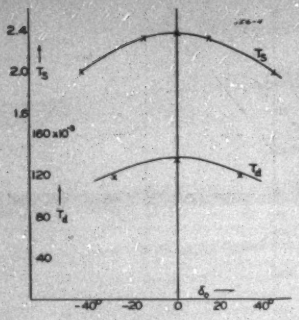

Figure 4

tory. The shape of this curve T_d is typical for the standard larger generators having a low-resistance damper winding. Here the influence of the negative damping is small, and the damping torque can be calculated by using equation 2 only.

The mathematical analysis used in deriving an expression for the damping torque also leads to the synchronizing torque. Since the equations for the synchronizing torque derived in the papers mentioned above (2, 4, and 5) are very complicated, a simple equation for the synchronizing torque was derived that corresponds to equation 2.[11] This equation is

$$T_s = \frac{ee_d}{x_d}\cos\delta_0 + e^2\frac{x_d - x_q}{x_d x_q}\cos 2\delta_0 + e^2\left[\frac{x_{1d}}{(1+r_{1d})Z_{1d}^2}\sin^2\delta_0 + \frac{x_{1q}}{(1+r_{1q})Z_{1q}^2}\cos^2\delta_0\right] \quad (7)$$

The results given by this equation will be compared with those obtained by Doherty and Nickle.[3] The curve T_s in figure 4 shows the comparison for $e_d = 1.6$. The agreement is very good, as has been found on other occasions. The correctness of equation 7 is proved by the results of experimental determinations of the natural frequency.

II. Tests to Determine the Damping Torque

There are very few tests published for determining the damping torque of a synchronous machine while the machine is hunting. Some valuable data are given by F. A. Hamilton.[16] Systematic tests, suggested by the author of this paper, were made by R. Kuenmich at the University of Stuttgart.[1] A small 4-pole, 1.6-kva, 50-cycle synchronous machine having an external field system was used in making these tests. The primary resistance was equal to 0.072; the material of the damper winding was copper. The damping torques are given in figure 5*B* for the machine without damper winding and in figure 5*A* for the machine with damper winding. Both diagrams reveal that the damping torque increases with increasing load and that it decreases with increasing excitation. It could not be expected, however, that this influence of the excitation would be appreciable in the large machines used by Hamilton in making his tests.

It follows from figure 5*B* that for the point $P = 0.2$ kw and $i_f = 1.66$ amperes, the torque $T_d = -14.1 \times 10^{-3}$. By using Park, the calculated torque under these conditions is found to be $T_d = -12.1 \times 10^{-3}$; by using the equations 2 and 6, it is found to be $T_d = -12.4 \times 10^{-3}$. The agreement is satisfactory, if it is considered that the accuracy of the tests is from ±10 to ±20 per cent. Figure 5*A* gives for the point $P = 1.6$ kw and $i_f = 1.66$ amperes, the torque $T_d = 9.3 \times 10^{-3}$. By using Park the calculated torque is found to be $T_d = 23.7 \times 10^{-3}$; by using the equations 2 and 6, it is found to be $T_d = 20.6 \times 10^{-3}$. The calculation does not check with the test. This is only partly a result of the limited accuracy of the tests. The main reason for the discrepancy is the difficulty of properly determining the constants of the machine, especially in the present case, where the saturation is high (the ratio of no-load AT to gap AT being equal 1.57).

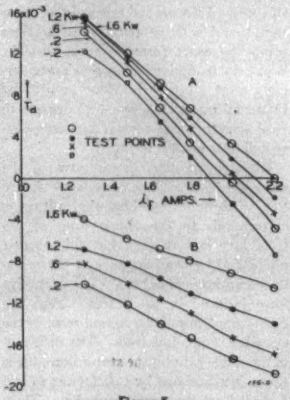

Figure 5

A—Damping torque with damper winding

B—Damping torque without damper winding

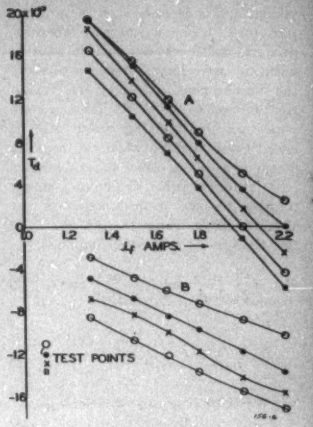

Figure 6

A—One ring open in the middle of the pole

B—One ring open in the middle of the interpolar space

In addition, the frequency of the oscillations is high and therefore the assumptions for the derivation of the formulas are not fully justified. The papers of Linville[7] and Waring and Crary[9] were used in calculating the constants. Only the constants of the damper winding were calculated in another way; namely, in the way shown by the author in a previous paper[12] (i.e., by introducing an equivalent value for the y of Linville).

Figure 6*A* shows the tested damping torques for the same machine, but with reduced influence of the damper winding in the quadrature axis. One of the rings has been cut in the middle of the interpolar space. The damping torque is negative over the entire range, as in figure 5*B* which refers to the machine without damper winding. Figure 6*B* shows the damping torques for the machine with one ring cut in the middle of the pole; i.e., with reduced influence of the damper winding in the direct axis. It is worth noticing that the torques are now larger than in figure 5*A* which refers to the machine with normal squirrel-cage damping. The reason for this can be seen from figure 2. The tested machine has a small angle δ_0 ($\delta_0 = 11.5°$ at 1.6 kw) and a small angle δ_0 may cause the negative damping in the direct axis to be stronger than the positive damping. In some cases (for example, when the machine is used for electric ship propulsion) it may be useful to cut the ring in the middle of the pole for this would reduce

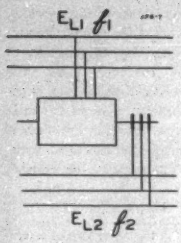

Figure 7

the short-circuit current without appreciably changing the damping torque.

Appendix

For the machine as per figure 7, it will be assumed that the stator voltage E_{L1} and the stator frequency f_1 are constant. All values will be reduced to terms of the stator. If the rotor rotates in the direction of the field produced by the stator currents:

$$n = \frac{120(f_1 - f_2)}{p} = \frac{120 f_1 (1-s)}{p} \qquad s = \frac{f_2}{f_1} \tag{1}$$

Assuming that the iron losses are negligible and that the vectors E_{L1} and E_{L2} are displaced by an angle δ, it is found that

$$\bar{Z}_1 = r_1 + jx_1 \qquad \bar{Z}_2 = r_2 + j_{sx_2} \tag{2}$$

$$E_{L1} = -E_1 + I_1 Z_1 \quad E_{L2} e^{-j\delta} = -sE_1 + I_2 Z_2 \tag{3}$$

$$I_m = I_1 + I_2 = jE_1 \frac{1}{x_m} \tag{4}$$

The author has shown in a previous paper[12] that it is useful to apply the "superposition principle" in treating the double-fed machine. With this principle, the stator current will consist of two parts, one produced by the stator voltage on the assumption that the rotor is short-circuited, the other produced by the rotor voltage on the assumption that the stator is short-circuited. The same is valid with reference to the rotor current. Thus

$$I_1 = I_{11} + I_{12} \qquad I_2 = I_{21} + I_{22} \tag{5}$$

From the equations 2 to 5 follow the four current components:

Stator:

$$I_{11} = E_{L1} \frac{f + jk}{l + jm}$$

$$I_{12} = -E_{L2} \frac{\cos\delta - j\sin\delta}{l + jm} \tag{6}$$

Rotor:

$$I_{21} = -E_{L1} \frac{s}{l + jm}$$

$$I_{22} = E_{L2} \frac{(\cos\delta - j\sin\delta)\left(1 + \tau_1 - j\frac{r_1}{x_m}\right)}{l + jm} \tag{7}$$

where

$$\tau_1 = \frac{x_1}{x_m}, \quad \tau_2 = \frac{x_2}{x_m}, \quad f = (1+\tau_1), \quad k = -\frac{r_2}{s}\frac{1}{x_m} \tag{8}$$

$$l = \left[(1+\tau_2)r_1 + (1+\tau_1)\frac{r_2}{s}\right] \times s$$

$$m = \left[x_1 + (1+\tau_1)x_2 - \frac{r_2}{s}\frac{r_1}{x_m}\right] \times s \tag{9}$$

The torque is given by the equation

$$T = E_{L2} \bullet I_1 - I_1^2 r_1 = jI_1 \bullet I_2 x_m \tag{10}$$

The dot ($\bullet$) indicates that the scalar product of the two vectors has to be taken. Thus

$$T = jI_{11} \bullet I_{21} x_m + jI_{11} \bullet I_{22} x_m + jI_{12} \bullet I_{21} x_m + jI_{12} \bullet I_{22} x_m \tag{11}$$

By evaluating these four scalar products and using the abbreviations

$$l_1 = \left[(1+\tau_2)r_1 - (1+\tau_1)\frac{r_2}{s}\right] \times s$$

$$m_1 = x_1 + (1+\tau_1)x_2 + \frac{r_2}{s}\frac{r_1}{x_m} \tag{12}$$

$$\tan\alpha = \frac{l_1}{m_1} \tag{13}$$

the equation 1 will be obtained.

List of Symbols

e_1, e_2	terminal voltage
E_L	line voltage
E_I	induced electromotive force
f_1, f_2	line frequency
f_p	frequency of the oscillation
I	current
I_m	magnetizing current
n	revolutions per minute
p	number of poles
r_1, r_2	resistance
r_{2d}	resultant secondary resistance in the direct axis
r_{Dq}	resistance of the quadrature-axis damper winding
s	slip
s_p	$\frac{Z}{\omega}$
T	torque
T_d	damping torque per radian angular displacement per second
x_{2d}	resultant secondary leakage reactance in the direct axis
x_{Dq}	leakage reactance of the quadrature-axis damper winding
x_{ad}	reactance of armature reaction in the direct axis
x_{aq}	reactance of armature reaction in the quadrature axis
x_d	$x_1 + x_{ad}$
x_q	$x_1 + x_{aq}$
x_1, x_2	leakage reactance
x_m	reactance due to the main flux
Z	angular frequency of the oscillation
$\boldsymbol{Z}$	impedance
δ_0	angular displacement between the axis of the rotor and rotating field corresponding to the average load
τ	leakage coefficient
ω	angular frequency of the line

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Control of the Switching Surge Voltages Produced by the Current-Limiting Power Fuse

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Synopsis: A new transient condition unique to fuses of the current-limiting type is described and it is recommended that these fuses be designed to inherently control switching surge voltage magnitudes to meet the following conditions:

1. The transient recovery voltage should not exceed the insulation level of rotating machines $\sqrt{3}(2E+1{,}000)$ where E is the rated terminal-to-terminal rms voltage of the lowest rated machine involved.

2. The transient recovery voltage should preferably not exceed the 60-cycle crest spark-over voltage of associated lightning arresters.

3. If the transient recovery voltage does exceed the 60-cycle crest spark-over voltage of associated arresters, the interrupting rating of the fuse should be determined and assigned to limit the arrester current to a safe magnitude.

These conditions may be met by current-limiting fuses employing conducting elements having two or more sections of different diameters. Such fuses have been designed and are now commercially available. Typical oscillograms illustrating the operation of these fuses are included.

Introduction

IT is generally recognized that most circuit-interrupting devices may be expected to produce a transient switching surge voltage having a magnitude appreciably in excess of the normal crest voltage. The magnitude of this transient voltage is a function of the characteristics of both the interrupting device and the circuit interrupted. To this background of existing and recognized transient voltage conditions may be added a relatively new phenomenon; the switching surge voltage (transient recovery voltage) of the current-limiting fuse.[1,2] This type of fuse tends to interrupt short-circuit currents so quickly that unless the interruption is properly controlled, the transient recovery voltage may reach a very high magnitude. With proper control, the transient voltage can be held within allowable safe limits.

The switching surge voltage of a current-limiting fuse differs from that of other interrupting devices in that the energy associated with the surge may be considerably greater. This difference results from the fact that the fuse limits the current by rapidly inserting arc resistance into the circuit at the instant the current-responsive element volatilizes. Since the high-resistance steady-state arc voltage of the fuse is practically equal to open-circuit voltage, the "recovery" occurs at the inception of the arc and *before* the interruption of the short-circuit current. With other interrupting devices, the voltage recovers at the end of the arcing period and *after* the interruption of the short-circuit current. Thus, the switching surge voltage of the fuse is associated with a definite value of dynamic short-circuit current and for this reason a new conception of the effects of transient recovery voltage must be considered.

The purpose of this paper is:

1. To call attention to the nature of a new switching transient phenomenon.

2. To point out the desirability of controlling the new switching transient to prevent damage to associated equipment.

3. To describe a method of designing current-limiting fuses with effective means of controlling switching surge voltages.

Permissible Limits for Switching Surge Voltages

Permissible limits for switching surge voltages should be based on several factors, one of which is the insulation level of rotating machines. Transformers and similar apparatus are considered to have an impulse ratio in the order of two or more, whereas rotating machines should be considered to have an impulse ratio only slightly greater than unity.[3] For

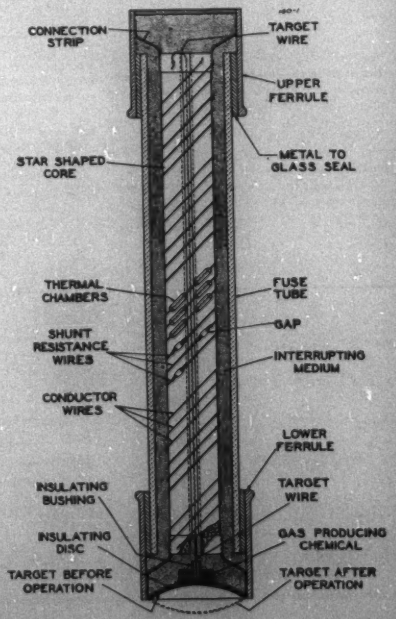

Figure 1. Current-limiting fuse with shunt-resistance wires

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The authors wish to acknowledge the parallel work of several European companies along the lines described in this paper. The contribution of K. A. Lohausen, Allgemeine Elektricitäts-Gesellschaft, is particularly noteworthy.

1. For all numbered references, see list at end of paper.

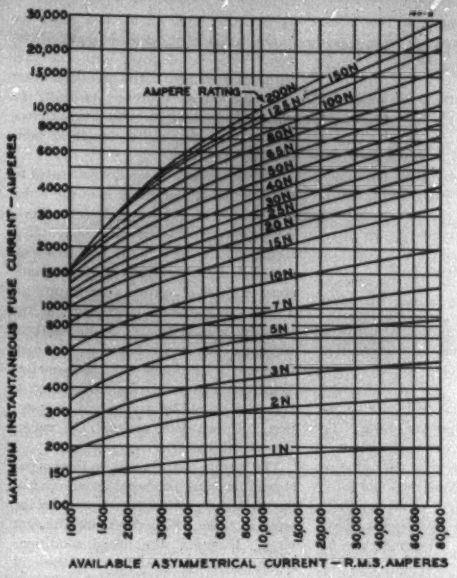

Figure 2. Maximum instantaneous current permitted by a line of current-limiting type fuses

the purpose of selecting permissible limits of switching surge voltage, safe practice will be adhered to by considering the crest value of the machine's one-minute high-potential test voltage as the maximum value of allowable transient voltage. The first logical limitation is then $\sqrt{2}(2E+1{,}000)$ where E is the rated terminal-to-terminal rms voltage of the lowest rated machine connected to the circuit in which the fuse is to be applied. For example, the limit for a 5,000-volt fuse is based on $E=4{,}000$ since this is the lowest rated machine in the 5,000-volt class. Since all other apparatus appears to have a higher insulation level than rotating machines, this limit should be entirely safe from a consideration of insulation alone.

A second and less obvious limit is imposed by the possibility of the operation of lightning arresters during voltage surges which would not damage insulation. The minimum 60-cycle spark-over voltage of an arrester is 1.5 times its maximum permissible line-to-ground voltage (proposed revision AIEE Standard 28) and its average spark-over voltage is somewhat higher. It is obviously desirable to minimize the number of arrester operations in all cases and to eliminate unnecessary operations wherever possible. Therefore, it becomes apparent that a desirable limit for switching surge crest voltages is 1.5 times the maximum crest rating of arresters used on the circuits for which the fuses are designed.

It has been found practical to design current-limiting fuses, as described later, to inherently limit switching surge voltages to magnitudes below the crest of the 60-cycle spark-over voltage of arresters which are rated above the voltage rating of the fuse. However, good engineering practice dictates the application of current-limiting fuses capable of interrupting line-to-line voltage whereas operating experience justifies the use of lower rated arresters on solidly grounded neutral systems. Therefore, since a line-to-line rated fuse may be expected to produce a switching surge voltage somewhat higher than the crest of normal line-to-line voltage, the associated line-to-neutral arrester is subject to spark over during every fuse operation. This condition does not exist when the fuses and arresters are *both* applied on the basis of line-to-line voltage.

When an arrester sparks over while a current-limiting fuse is interrupting a circuit, the two devices divide the dynamic short-circuit current in inverse proportion to their respective resistances. As previously pointed out, this current may be considerably higher than that ordinarily associated with switching surge voltages and its duration may be in the order of 1,000 to 1,600 microseconds. The ability of an arrester to pass current for relatively long periods of time is limited by economic considerations and this limit is recognized in AIEE Standard No. 28. It therefore becomes advisable to determine and assign interrupting ratings to fuses in a way that the short-circuit currents permitted by the fuses, when arresters are subject to spark over, are limited to values such that the arresters may safely pass their share of current without damage to the arresters.

From the considerations discussed above, it may be concluded that fuses of the current-limiting type should be so designed that switching surge voltages are inherently controlled to meet the following conditions:

1. The transient recovery voltage should not exceed the insulation level of rotating machines $\sqrt{2}(2E+1{,}000)$ where E is the rated terminal-to-terminal rms voltage of the lowest rated machine involved.

2. The transient recovery voltage should preferably not exceed the 60-cycle crest spark-over voltage of associated lightning arresters.

3. If the transient recovery voltage does exceed the 60-cycle crest spark-over voltage of associated arresters, the interrupting rating of the fuse should be determined and assigned to limit the arrester current to a safe magnitude.

Designing Current-Limiting Fuses to Control Switching Surge Voltages

One method of controlling transient recovery voltages to meet specified limits has been used for two years in commercially available fuses. It consists essentially, figure 1, of resistance wires, in parallel with the conducting wires, through which the energy of the surge is shunted and absorbed. The currents which the shunt-resistance wires must handle are shown as the ordinates of the curves of figure 2. The practical application of this principle appears to be limited to fuses rated approximately ten amperes and below as the required ability of the shunt-resistance wires to absorb surge energy increases rapidly as the continuous-current ratings of the fuses increase. Since the shunt-resistance wires occupy space and serve no useful purpose during normal current conditions, it is obvious that the fuses may be made smaller and less costly by combining the voltage limiting and current-carrying functions. This desirable result may be obtained by controlling the growth of arc resistance during the interrupting process. The conducting elements, schematically shown in figure 3, form a basis for the reliable control of arc resistance.

The resistance of an arc is a function of its diameter, length, and the magnitude of current in the arc. The voltage which appears across the fuse at any instant during current interruption is the product of the arc resistance and arc current at that instant. Neglecting other circuit resistance which may be present, this condition may be expected by the fundamental equation

$$e = ri + L\frac{di}{dt} \qquad (1)$$

where

e = generated voltage
r = arc resistance
i = arc current
L = circuit inductance
t = time

Therefore, it is apparent that the rate and amount of arc resistance inserted in the circuit determines the rate of rise and magnitude of the transient recovery voltage.

When the available short-circuit current is of such magnitude that the current is appreciably limited by the fuse, it has been found empirically that the arc resistance of the fuse at the instant of surge voltage crest, is directly proportional to the arc length. The arc length at any instant is in turn equal to the length of the conducting element which has been volatilized. The number and diameter of the conducting elements volatilized also influence the arc resistance, at the instant of surge voltage crest, as indicated by the following empirical equation:

$$r = [K_1 - (K_2 + K_3 d^2)\sqrt{n}]l \qquad (2)$$

where

r = arc resistance at instant of surge voltage crest
d = diameter of conducting elements
n = number of conducting elements
l = arc length
K_1 K_2 K_3 = constants

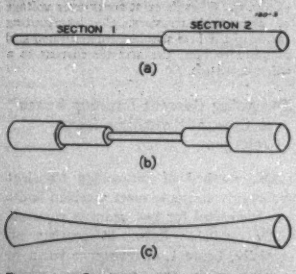

Figure 3. Conducting elements (schematic) showing use of progressive steps in cross section

The surge voltage crest may then be expressed as

$$V = ir = i[K_1 - (K_2 + K_3 d^2)\sqrt{n}]l \qquad (3)$$

Where i is the instantaneous current at surge voltage crest as given by the curves of figure 2.

Since the values of d and n are fixed within narrow limits by the continuous-current rating and the interrupting rating of any given fuse[4] and since the maximum value of i is also determined by the interrupting rating of the given fuse, equation 3 reduces to the simple form:

$$V = Kl \qquad (4)$$

The accuracy of equation 4 has been established by hundreds of comparative interrupting tests. This equation provides the basis for a new and effective method of controlling switching surge voltages of current-limiting fuses. To hold the crest voltage to a value V_1, it is only necessary to determine the value of K for the fuse rating concerned and solve equation 4 for the length of the conducting element, l_1, which may be vaporized at the time V_1 occurs. The length of conducting element so determined may be, and in most cases is, less than the minimum length required to safely interrupt the circuit. Therefore, it is necessary to provide additional conducting element length which, when vaporized, will produce sufficient additional arc resistance to effect interruption.

To prevent the crest voltage produced by the added length of element from superimposing itself on the first crest, the vaporization of the added length of element must be delayed until the first surge has declined. The necessary delay may be obtained readily by designing the added element length with a larger cross section than the original length as indicated in figure 3a.

The time required for the first surge to reach its crest and decay is in the order of 100 to 150 microseconds with short-circuit current at or near the interrupting rating of the fuse. This fact has been established by hundreds of short-circuit tests on fuses of various current ratings. Typical cathode-ray oscillograms of the transient voltage conditions during these tests are shown in figure 4. It may therefore be concluded that the diameters of the two sections of conducting element, figure 3a, should be so designed that section 2 is vaporized at least 150 microseconds after section 1.

The factors contributing to the magnitude of the surge produced by section 2 of the conducting element are essentially the same as those which determine the first surge. However, the initial conditions for the second surge differ from those of the first surge in that the short-circuit current has declined to a lower value and the initial voltage is at least equal to the normal frequency voltage at that instant. With these exceptions, the maximum length of section 2 may be determined from equation 4 with the proper evaluation of constants. The optimum element design is that which gives the minimum

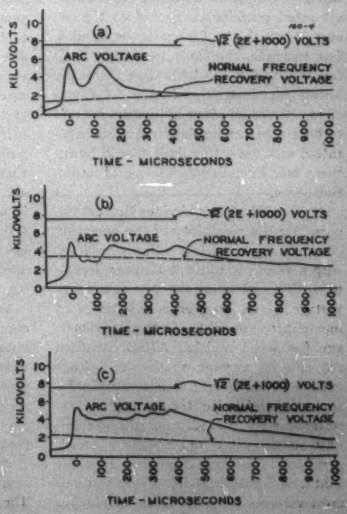

Figure 4. Typical oscillograms of controlled transient recovery voltage produced by current-limiting fuses

(a)—Fuse rating—2,500 volts, 10 amperes
Test voltage—2,500 volts
Available rms current—21,000 amperes
Phase angle of generator voltage at time of first surge crest—24 degrees

(b)—Fuse rating—2,500 volts, 40 amperes
Test voltage—2,500 volts
Available rms current—23,000 amperes
Phase angle of generator voltage at time of first surge crest—90 degrees

(c)—Fuse rating—2,500 volts, 100 amperes
Test voltage—2,500 volts
Available rms current—27,000 amperes
Phase angle of generator voltage at time of first surge crest—145 degrees

A Vertical-Flow Outdoor Compressed-Air Breaker

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1. Introduction

THE elimination of oil in indoor circuit breakers, particularly for powerhouse use, has been insistently demanded to reduce fire hazard. In an effort to meet these requirements, various types of breakers not containing oil have been built and studied. Self-contained breakers of the "De-ion" type[1] have been available for several years, and the potentialities of water breakers[2] have been carefully investigated. Compressed-air breakers[3] for this service have been successfully developed, particularly to meet high kilovolt-ampere interrupting requirements, and the circuit-rupturing ability of these devices has been so amazingly efficient that experimental breakers using this principle have now been built and tested for high-voltage outdoor application.

2. Interruption With Compressed Air

Compressed-air breakers for interrupting medium powers have been in use in Europe for ten years, but these devices have not been available in America until recently. The longitudinal flow-type interrupter, generally used in Europe, was investigated and found to be very satisfactory for moderate values of current, but its inherent limitations made it impractical for the medium and high kilovolt-ampere requirements at powerhouse voltages. On the contrary, an interrupter using a blast of compressed air and insulating splitters disposed perpendicular to the arc, was found to be very effective and not subject to the same arc-current limitations. Structurally, it was also found well adapted for use with high-current carrying contacts.

Just one year ago, the $1^1/_2$-million kva, 15-kv compressed air circuit breaker[3] of the transverse-flow type was reported, and oscillograms of single-phase operations at 13.2 kv up to 65,300 amperes rms were shown. Since then, the same $1^1/_2$-million kva breaker has been successfully demonstrated at 13.2 kv, 3 phase up to 86,500 amperes, and this type of interrupter is now being built into a $2^1/_2$-million kva, 15-kv breaker for 4,000 amperes continuous current-carrying capacity. Currents in excess of 100,000 amperes can be interrupted with this breaker using tank pressures not greater than 150 pounds per square inch.

The theory of this interrupting process in breakers of this type has been studied. The effectiveness of the cross-blast, splitter-type interrupter appears to depend on, first, the fact that a number of interrupting elements or splitters can easily be used in series, and second, the use of a gas-forming material such as fiber for the splitter. The function of the gas-forming splitter elements is largely to introduce turbulence into the arc stream to enhance the deionization by diffusion, following a current zero. Slepian[4] has described this theory in detail.

As breaker voltages are increased from 15 kv or 34 kv, the problem of insulation becomes of increasing significance and it becomes more difficult to design a satisfactory structure which operates on the cross-blast principle. Fortunately, the currents to be interrupted decrease as the voltage increases but not to a sufficient extent so that plain metallic nozzle interrupters can be used with moderate air pressure. Consequently, for the higher voltages it has been necessary to develop a new type of interrupting element which lends itself to vertical porcelain-clad breaker construction and provides high-interrupting ability.

3. Vertical-Flow Compressed-Air Interrupter

The reasons cited for the success of the cross-blast interrupter suggest that a satisfactory form of device can be built for higher voltages by using fiber disks horizontally disposed. These disks have central orifices through which the arc is drawn and through which a vertical flow of air passes to effect the interruption. One or more of such elements can be placed in series, and a dual interrupter of this type is shown in figure 1. It consists of two fiber disks with a metal insert in the center. These inserts have centrally located holes which form the orifices. Between these orifice disks another

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1. For all numbered references, see list at end of paper.

voltage at any instant during interruption. This condition exists, other factors being equal, when both surges reach the same crest magnitude.

The desired limit of switching surge voltage cannot always be met, and successful interruption obtained, by the simple two-section conducting element. In such cases, it is necessary to extend the same design principles to include multisection conducting elements similar to that shown in figure 3*b*. Carried to its logical extreme, this procedure would result in conducting elements characterized by a smooth taper as indicated in figure 3*c*. However, from practical economic and manufacturing considerations, these tapered elements cannot yet be justified.

Conclusion

The control of fuse switching surge voltages by the use of conducting elements with uniform sections of different diameters has proved both practical and flexible. Current-limiting fuses employing this principle have been designed and are now commercially available. Comprehensive tests have shown that these fuses consistently limit the switching surge voltages to magnitudes within the acceptable levels given in the first part of this paper.

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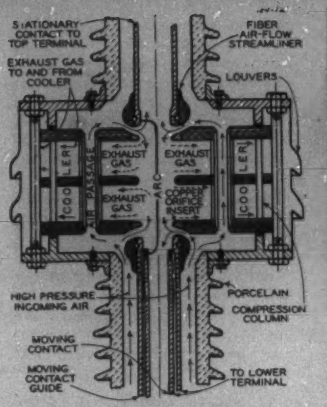


Figure 1. The interrupting element of a 138-kv vertical-flow outdoor compressed-air circuit breaker

(Above) Schematic diagram showing air flow

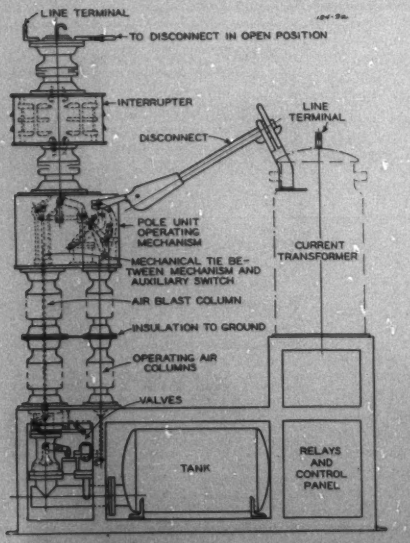
(Right) Photograph of interrupter and contact after heavy duty tests shown in tables I and II

insulating plate is introduced which restrains the random motion of the arc in the exhaust gas. The interrupter is symmetrical about this insulating plate so that the stationary contact and the upper orifice form one working unit. Likewise, the moving contact and the lower orifice plate form another. The contact members are hollow to permit a portion of the air blast to pass through them. The metal inserts in the fiber disks are used to lessen erosion and enlargement of the hole in the disks.

The air blast passes through the porcelain below the interrupter where part of it escapes through the lower working unit. The remainder passes through the tubes in the interrupter to the upper porcelain from which it escapes through the upper working unit. The air, as shown in figure 1, approaches the arc in a radial direction from between the orifice plate and the streamliner of the contact. Upon reaching the arcing space, it turns and flows vertically along the arc stream, some of it escaping through the contact, while the greater portion escapes through the orifice plate.

It has been found experimentally that this combination is better than a solid conductor and an orifice, or two orifices with equal discharge area. The unsymmetrical flow of air serves to eliminate a "dead spot" in the center which is not readily deionized, and likewise the arc terminal is carried into the hollow of the contact, so that the flow of air carries the metallic vapor from the arc terminal out into the vent instead of into the restricted portion of the arc path where the growth of dielectric is the greatest. The smaller quantity of gas which is discharged through the contacts escapes out the top of the breaker and into the mechanism box. The greater amount which passes through the orifices escapes radially between the orifice plates and is cooled by the screening placed in the annular space formed by the two orifice plates, the air tubes, and the pin supports.

This very simple arrangement gives in reality two interrupting or working combinations in series. The first, consisting of the stationary contact and the upper orifice, which becomes effective with the first third of the contact motion.



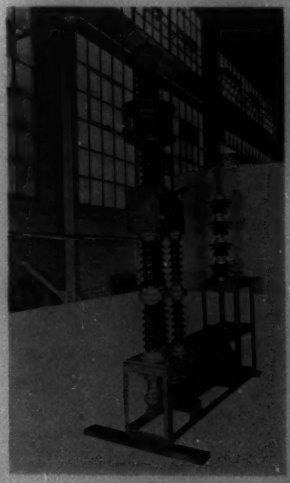


Figure 2. Single-pole 138-kv vertical-flow outdoor compressed-air circuit breaker

(Left) Schematic diagram

(Right) Photograph of breaker mounted in the high power laboratory

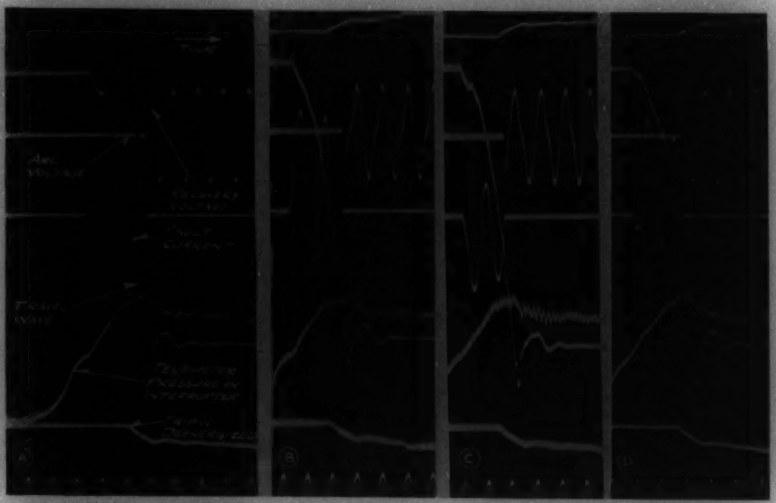


Figure 3. Magnetic oscillograms from table I. Current and voltage values noted are rms values per AIEE Standards

A—Fault current, 5,840 amperes recovery voltage, 123 kv

B—2,520 amperes, 123 kv

C—7,150 amperes, 123 kv

D—8,900 amperes, 123 kv

The second, consisting of the moving contact and the lower orifice, which becomes effective during the last third of the contact motion. In practically every interruption, with currents, voltages, and voltage-recovery rate typical of commercial applications arc extinction is obtained in the first working unit.

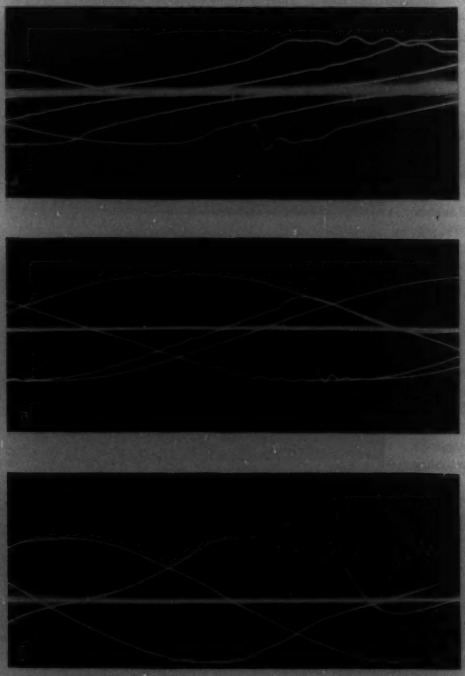


Figure 4. Cathode-ray oscillograms corresponding to those in figure 3

A—Fault current 2,520 amperes rms. Restored voltage 123 kv. Oscillatory frequency 2,600 cycles per second. Recovery rate 1,750 volts per microsecond. Maximum instantaneous voltage 296 kv

B—Fault current 5,840 amperes rms. Restored voltage 122 kv. Oscillatory frequency 3,660 cycles per second. Recovery rate 2,310 volts per microsecond. Maximum instantaneous voltage 264 kv

C—Fault current 8,900 amperes rms. Restored voltage 123 kv. Oscillatory frequency 4,310 cycles per second. Recovery rate 2,970 volts per microsecond. Maximum instantaneous voltage 295 kv

4. 138-Kv Compressed-Air Breaker

Figure 2 shows both a photograph and a schematic diagram of a single-pole unit 138-kv experimental breaker. The usual air storage tank is mounted in a simple frame which also houses the electrical relaying equipment, blast valve, and valves to supply air for opening and closing the breaker. The air-blast valve is mechanically interlocked with the opening valves so that the contacts cannot part without sufficient air for arc extinction. The operating valves are also interlocked pneumatically so that the opening operation always takes preference over the closing operation. The blast valve located adjacent to the tank discharges into a hollow porcelain insulator which carries the air direct to the interrupter chamber with a minimum of length and turns. The operating mechanism is at line potential when the isolating disconnect switch is closed and engaging the current transformer or the top of a post insulator which forms the one line terminal. The other line terminal is at the top of the breaker. The interrupting element is halfway both electrically and mechanically between the top terminal and the operating mechanism. When the breaker is in the open position, the disconnect removes potential from the interrupter and short-circuits it by engaging suitable clips at the

Figure 5. Magnetic oscillograms from table II. Current and voltage values noted are rms values per AIEE Standards

A—Fault current, 2,800 amperes. Recovery voltage, 65 kv

B—8,100 amperes, 64 kv

C—11,200 amperes, 63 kv

D—13,900 amperes, 62 kv

top. The disconnect is mechanically interconnected to the interrupting contact and both are operated by an air piston moving in a cylinder located in the pole-unit mechanism box. Air for operating this piston is transmitted from the tank through valves at ground potential, and thence through hollow porcelain insulators, one for closing and one for opening. These two porcelains with the third and larger one which carries the air blast from the tank to the interrupter, form a supporting tripod and the insulation to ground. The mechanical linkage between the operating cylinder, interrupting contacts, and disconnecting member are such that in normal service the disconnect opens last on an opening operation and closes first on a closing operation.

The interrupting contact consists of a simple rod which slides within two tulip-type contacts, one supported from the mechanism box and the other from the top of the breaker, both extending toward the interrupting element which is centrally located. The arc is drawn from the upper stationary contact, downwardly through the interrupter, where it is subjected to the air blast.

The breaker is ideal for high-speed reclosing duty because of efficient disposal of ionized gases from the interrupter and the high mechanical speed of the air-operating mechanism. In case of reclosure, the disconnecting switch is not opened; the contacts are simply parted in the air blast, the arc is interrupted and the contacts are reclosed before the air blast is turned off.

This type of construction provides porcelain insulation to ground of the current-carrying parts and air isolation between terminals when the breaker and disconnect are in the open position. There are no heavy operating rods with potential across them, since the entire mechanical effort is transmitted through the medium of air flow in the porcelain columns. Contacts, interrupter, and mechanisms are very accessible and easily maintained. Provision for a porcelain-

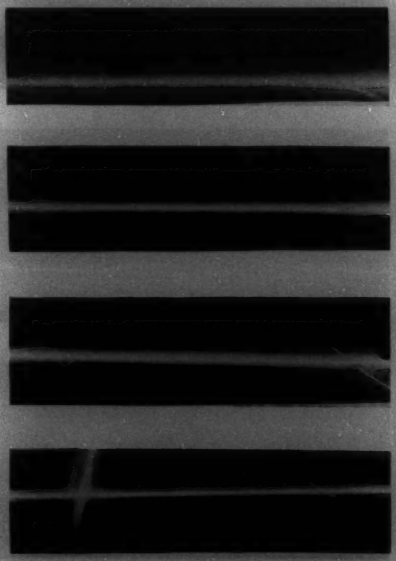


Figure 6. Cathode-ray oscillograms corresponding to those of figure 5

A—Fault current 2,800 amperes rms; restored voltage 65 kv. Oscillatory frequency 3,270 cycles per second; recovery rate 1,225 volts per microsecond. Maximum instantaneous voltage 157 kv

B—Fault current 8,100 amperes rms; restored voltage 64 kv. Oscillatory frequency 4,900 cycles per second; recovery rate 1,830 volts per microsecond. Maximum instantaneous voltage 124 kv

C—Fault current 11,200 amperes rms; restored voltage 63 kv. Oscillatory frequency 6,600 cycles per second; recovery rate 2,440 volts per microsecond. Maximum instantaneous voltage 135 kv

D—Fault current 13,900 amperes rms; restored voltage 62 kv. Oscillatory frequency 9,780 cycles per second; recovery rate 3,570 volts per microsecond. Maximum instantaneous voltage 135 kv

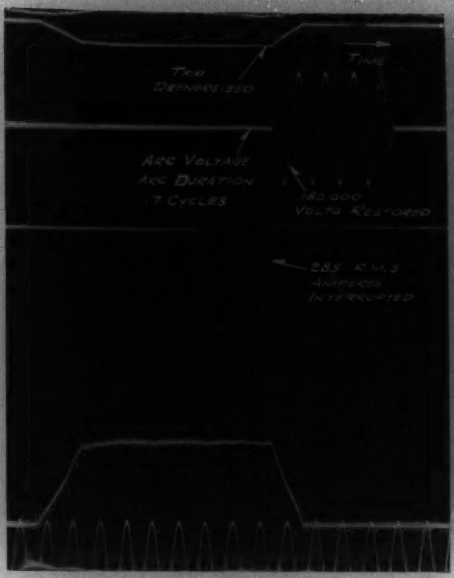


Figure 7. Magnetic oscillogram of 138-kv single-pole unit interrupting low current at 180 kv

Figure 8. Typical interruption of transformer magnetizing current

clad current transformer is made on the disconnect end of the breaker. The pole units of a three-phase breaker are separate and distinct, and may be arranged for individual phase operation if desired. On the other hand, co-ordination of the three poles is possible by interlocking the air valves in obvious ways.

5. Experimental Test Results

Tables I and II show the results of two typical series of single-phase tests on the single-pole unit, 138-kv compressed air circuit breaker shown in figures 1 and 2. The highest of these tests represents power equivalent to slightly in excess of 2,000,000 kva on the basis of an ungrounded three-phase 138-kv system. The current on this film (figure 3) was unsymmetrical and thus contained considerable d-c component. On the basis that 127 kv is the line-to-neutral voltage of a grounded neutral system, the three-phase power equivalent is over 3,250,000 kva.[4,6]

Table I shows the results of a series of 18 tests at 132-kv applied voltage on the single-pole unit, 138-kv breaker at current values between 270 and 8,900 amperes. The restored voltage varied from 132 kv to 121 kv. The air pressure in the storage tank of the breaker varied from 210 to 230 pounds per square inch. The arcing time varied from 0.6 to 2.1 cycles. This variation indicates that in many of the operations even at 132 kv, the interruption was completed in the upper working unit without waiting for the arc to be drawn into the lower one. Figure 3 shows three typical oscillograms; one at 2,520, 5,840, and 8,900 amperes respectively. From the travel wave it is apparent that the 8,900 amperes was interrupted in the upper working unit which consists of one orifice and one contact, spaced less than one inch apart. Figure 4 shows the three cathode-ray oscillograms corresponding to the magnetic oscillograms in figure 3. The highest oscillatory frequency shown is 4,310 cycles per second, which occurred on the 8,900-ampere test. This corresponds to a recovery rate of 2,970 volts per microsecond. However, in table I frequencies as high as 4,620 cycles per second, or 3,180 volts per microsecond are recorded.

Table II shows the results of a series of tests at 66 kv and current values varying from 2,800 amperes to 13,900 amperes. Again all tests were single phase on the single-pole 138-kv unit shown in figure 2. The air pressure in the breaker storage tank varied from 210 to 230 pounds per square inch. The arcing time varied from 0.7 to 1.2 cycles. In all cases the circuit was interrupted without assistance from the lower working unit. Figure 5 shows the magnetic oscillograms for tests 1, 3, 5, and 7 of table II. Figure 6 shows the cathode-ray oscillograms corresponding to the magnetic oscillograms in figure 5. The oscillatory frequency of the 66-kv circuit was considerably higher than that of the 132-kv circuit. As recorded, these values varied from 3,270 to 9,780 cycles per second. This frequency resulted in a recovery rate which varied from 1,225 to 3,570 volts per microsecond, which is slightly in excess of that obtained on the 132-kv circuit when adjusted for minimum impedance.

Figure 7 shows the magnetic oscillogram of the upper working unit of the 138-kv breaker interrupting low current at 180 kv. Also, successful interruption of low values of current on a highly inductive circuit has been obtained up to 264 kv, but not until the arc was drawn into the second or lower working unit.

Figure 8 shows the magnetic oscillogram of the 138-kv pole unit interrupting the magnetizing current of two single-phase power transformers in parallel, each connected for 13.2 to 132 kv, 3.3 per cent impedance and 33,333 kva, giving a total current for both transformers of approximately 20 amperes. The circuit consisted of a 13.2-kv genera-

Table I. Opening Tests on an Experimental Compressed-Air Circuit Breaker

132-Kv Initial Voltage Applied to a Single-Pole Unit of a 138-Kv Circuit Breaker, 60 Cycles

Test Number	Recovery Voltage (Kv)	Amperes Interrupted	Tank Pressure	Arcing Time (Cycles)	Oscillatory Frequency (Cycles Per Sec.)	Test Transient Recovery Rate (Volts Per Microsec.)	Circuit Transient Recovery Rate (Volts Per Microsec.)
1	132	270	210	0.9			
2	130	910	210	0.8			
3	128	1,140	230	1.0			
4	124	1,340	230	1.0			
5	127	2,160	210	0.6			
6	126	2,290	230	0.6	2,430	1,700	1,750
7	123	2,520	230	1.2	2,600	1,750	1,880
8	123	3,200	230	2.1	2,170	1,865	2,000
9	123	3,300	230	1.4			
10	122	4,200	230	1.8	3,550	1,960	2,120
11	123	4,230	210	1.2			
12	122	4,570	230	0.8	3,280	2,010	2,170
13	123	5,600	220	1.2			
14	122	5,840	230	1.2	3,660	2,310	2,500
15	123	5,900	220	1.9	4,060	2,490	2,670
16	123	7,150	230	0.8	4,620	3,180	3,420
17	121	8,250	230	2.0	4,380	2,620	2,860
18	123	8,900	230	0.8	4,310	2,970	3,190

Table II. Opening Tests on an Experimental Compressed-Air Circuit Breaker

66-Kv Initial Voltage Applied to a Single-Pole Unit of 138-Kv Circuit Breakers, 60 Cycles

Test Number	RMS Amperes Interrupted	Cycles of Arcing	Restored Voltage	Air Pressure in Tank (Pounds Per Square Foot)	Circuit Oscillatory Frequency (Cycles Per Sec.)	Test Transient Recovery Rate (Volts Per Microsec.)	Circuit Transient Recovery Rate (Volts Per Microsec.)
1	2,800	0.7	65	210	3,270	1,225	1,243
2	5,500	0.8	65	210			
3	8,100	0.7	64	210	4,900	1,830	1,890
4	10,000	1.2	64	210			
5	11,200	1.0	63	210	6,600	2,440	2,550
6	12,200	0.8	64	210			
7	13,900	1.2	62	230	9,780	3,570	3,800

tor feeding a 13.2 to 132-kv transformer. In series with this transformer was the test breaker and the 132-kv windings of the unloaded transformers just described. Tests were made both with one and with two transformers for the load. In all cases the current was interrupted promptly in about one-half cycle, as shown in figure 8.

6. Conclusions

The general acceptance in this country of compressed air as an interrupting medium for low-voltage heavy-duty powerhouse breakers has stimulated interest in its application to outdoor high-voltage breakers.

Experimental evidence has shown that while the continuous current-carrying requirements and heavy interrupting duty of powerhouse breakers dictate a design using splitters and transverse flow, the vertical-flow type of interrupter may be employed to advantage for porcelain-clad outdoor high-voltage breakers.

Tests on a new type of vertical-flow interrupter indicate that it can be developed to handle the maximum kilovolt-ampere requirements at 69 kv and above. A comparison of table I and table II suggests that if approximately 14,000 amperes at 68 kv and 5,370 volts per microsecond can be successfully handled on one-half of the interrupter, currents considerably in excess of 8,900 amperes at 132 kv may be expected to carry this type of interrupter far into the future kilovolt-ampere requirements.

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Development of the Glow-Switch

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THE glow-switch[1] is an automatic switch for starting fluorescent lamps.[2] It is unique in that it is a thermal switch without a heater element, the heat being supplied by a glow discharge. The glow-switch functions as a time-delay relay yet it is a single-element switch with only two leads. At one value of applied voltage its resistance becomes a fraction of an ohm, while at a voltage only slightly lower, its resistance is measured in megohms. Before proceeding with the story of the development of the glow-switch, it is in order to discuss briefly the task which it performs.

Once the discharge is started, a fluorescent lamp can be operated from an a-c supply whose voltage is approximately twice lamp voltage. The lamp must be operated in series with an impedance, usually an inductance, to limit the current.[3] The most commonly used circuit is shown in figure 1. A voltage considerably higher than the supply voltage is necessary to start the discharge. The discharge should not be started until after the lamp cathodes have been heated to a temperature at which they can emit the necessary supply of electrons without entailing excessive positive ion bombardment. The glow-switch serves to automatically connect the lamp cathodes in series until they are heated to operating temperature, and then to break the connection, and subject the lamp to a transient voltage sufficiently high to start the discharge.

The glow-switch, figure 5, consists of a glass bulb, filled with an inert gas and containing a pair of contacts operated by thermostatic bimetal. Initially the contacts are open and the supply voltage appears across the switch. The supply voltage is sufficient to establish in the switch a glow discharge which heats the bimetal and causes the contacts to close. The current passed by the glow discharge is only a few milliamperes and does not cause any appreciable heating of the lamp cathodes, but when the contacts close, the current is limited only by the series inductance and the resistance of the cathodes. The cathode-heating current is approximately $1^1/_2$ times normal lamp current and it quickly heats the cathodes to operating temperature. While the contacts are closed, the glow discharge is extinguished so that the bimetal cools and after a short-time delay, during which the lamp cathodes are heated, the contacts open. Opening of the contacts suddenly interrupts the current and induces in the series inductance a transient voltage sufficiently high to start the arc through the lamp. After the lamp is started the cathodes are self-heating and the voltage across the lamp is insufficient to re-establish the glow discharge in the switch. The contacts remain open and the switch consumes no energy. If for any reason the lamp does not start the first time the contacts open, the cycle is quickly repeated.

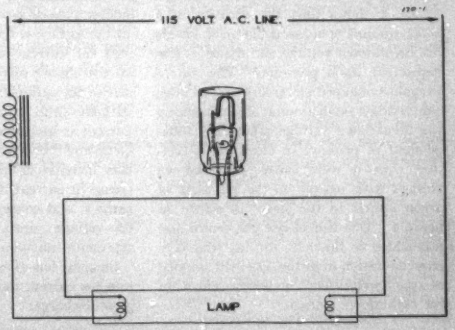

Figure 1. Fluorescent lamp circuit

The requirements that must be met by the glow-switch are as follows:

(1). The breakdown voltage for the glow discharge must be less than supply voltage and greater than lamp voltage.

(2). The contacts must close quickly.

(3). The contacts must remain closed for a period of time sufficient to allow the lamp cathodes to reach operating temperature.

(4). The switch must interrupt the current quickly so that the transient voltage induced in the series inductance will be sufficiently high to start the lamp.

(5). The switch must be small and inexpensive.

Breakdown Voltage

The breakdown voltage, or the voltage at which the glow discharge starts, must be less than the lowest supply voltage with which the glow-switch is to be used, and must be safely above peak lamp voltage so that the switch will not glow and the contacts will not close after the lamp starts. The *T*-12, 15-watt, the *T*-8, 15-watt, and the *T*-12, 20-watt lamps operate at 48, 56, and 62 volts respectively, and all three lamps are for operation from a supply of 118 volts ±10 per cent. The same glow-switch is used with all three lamps. The voltage wave form for a fluorescent lamp is nonsinusoidal, and at low current the voltage is abnormally high. The peak voltage for a 20-watt lamp operating from minimum allowable supply voltage is equal the peak value of a sinusoidal voltage of 70 volts. Accordingly, the minimum breakdown voltage was set at 75 volts alternating current, and the voltage necessary to start the glow discharge and cause the contacts to close in a reasonable time was set at 105 volts.

It was found that neon containing a small amount of argon, used with electrodes coated with magnesium, gave a minimum breakdown voltage just greater than the minimum allowable limit. The breakdown voltage should not vary greatly with respect to gas pressure, gas mixture, or electrode separation, so that reasonable tolerances can be allowed in manufacture, and so that breakdown voltage will be relatively independent of pressure changes due to gas cleanup during the life of the switch. Curve *A* of

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Credit for development of the glow-switch to its present form is shared by D. S. Gustin, W. E. Carpenter and the author, all of whom are members of the engineering department, vapor lamp development section, of the Westinghouse lamp division at Bloomfield, N. J.

1. For all numbered references, see list at end of paper.

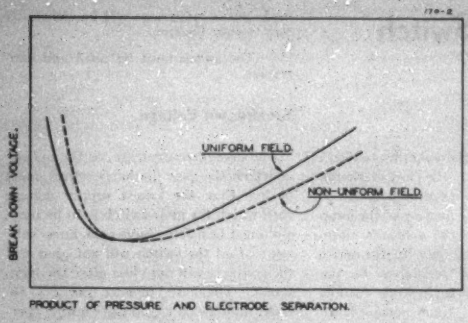

Figure 2. Breakdown voltage

With respect to gas pressure and electrode separation for (*A*) parallel plane electrodes, and (*B*) irregularly shaped electrodes (Slepian)

figure 2 shows how breakdown voltage varies with respect to the product of gas pressure and electrode separation for a glow discharge between plane parallel electrodes.[4] Curve *B* shows the effect of a nonuniform field obtained by using electrodes of irregular shape. Fortunately, a nonuniform field makes the break-down voltage less dependent upon the product of pressure and electrode separation at values greater than that corresponding to minimum breakdown voltage. Figure 3 shows that the addition of a small amount of argon to the neon lowers the breakdown voltage and makes it less dependent upon pressure.[5] The use of irregularly shaped electrodes and of neon containing a small amount of argon makes the breakdown voltage practically independent of pressure or electrode separation over a wide range. Breakdown voltage with respect to the per cent of argon added to the neon[5] is shown in figure 4. One-half of one per cent argon was added to the neon so that relatively large deviation from the specified amount of argon would have no serious effect on the breakdown voltage.

Fast Closing of the Contacts

The contacts can be made to close quickly by the use of a sensitive bimetal element, by using closely spaced contacts, by using a bimetal element with minimum heat capacity, and by producing a high-current density at the surface of the bimetal when it serves as cathode for the glow discharge. Sensitive bimetal and close contact spacing result in closure of the contacts upon a slight rise in temperature. The temperature of the bimetal necessary for closing the contacts should be as high as 100 degrees centigrade, so that operation will be relatively independent of room temperature. A sensitive bimetal element is necessarily long and thin, and consequently, the force per unit deflection of the contact is small. If the bimetal element is sensitive and the contact spacing is small, there will be little force available to pull the contacts apart when they stick. The bimetal should be short and only as thick as necessary to obtain the required rigidity so that the heat capacity will be low. The most desirable method of increasing speed of operation is that of increasing the current density.

For a normal glow discharge the cathode-voltage drop and the current density at the surface of the cathode are constant, and the current density is proportional to the square of the gas pressure. The size of the cathode spot increases, but the cathode drop remains constant as the current is increased until the cathode is completely covered by the glow. Further increase in current demands an increase in current density at the cathode surface, and causes an increase in cathode-voltage drop. Such a condition represents an abnormal glow discharge.

Slepian[4] has given the following equation for current density for an abnormal glow discharge:

$$J = J_0 + K(E - E_0)^2 P^2 \qquad (1)$$

$$J_0 = BP^2 \qquad (2)$$

where J is current density; J_0, normal current density; E, cathode drop, E_0, normal cathode drop; P, gas pressure; and B and K are constants. This equation shows that to cause rapid closing of the contacts by producing a high-current density, the gas pressure must be high, E_0 must be as low as permissible, and E must be high. For a neon-argon mixture in a nonuniform field, and PD greater than the critical value, E_0 is practically equal the breakdown voltage, the value of which has already been determined. E is equal the supply voltage minus the IZ drop in the inductance and the lamp cathodes. Obviously, E will be a maximum only if the current drawn by the glow discharge is a minimum. A high-current density and yet a small current can be obtained only by the use of a small cathode-surface area. Then, for rapid closing of the contacts, the gas pressure must be high, and the bimetal element must be as small as is practical from the standpoint of manufacture.

Time Delay

The contacts must remain closed for a period of time sufficient to allow the lamp cathodes to reach operating temperature. For 15- and 20-watt fluorescent lamps this time is approximately one second. The time delay is produced by the inevitable sticking of the contacts and by nonuniform heating of the bimetal, which results from the use of high gas pressure.

Transient Voltage for Starting the Lamp

When the contacts open, there must be induced in the series inductance a transient voltage of sufficient magnitude and duration to start the lamp. It is impos-

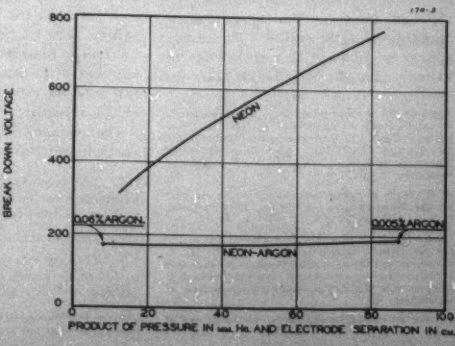

Figure 3. Breakdown voltage

With respect to gas pressure and electrode separation for pure neon and for a mixture of neon and argon (Penning)

sible to interrupt a current through an inductance instantaneously. For an instant after the contacts open, the inductance forces the current to continue flowing at a value practically equal to that of the instant before the contacts opened. The current continues to flow and decreases in magnitude as the energy stored in the magnetic field of the series inductance is dissipated. Then, until the lamp starts, the voltage across the glow-switch and across the lamp is the voltage corresponding to the current flowing through the switch whose contacts are open. Current can continue flowing through the switch after the contacts separate because of arcing at the contacts and re-establishment of the glow discharge. As the contacts separate, the current is carried by one point on each contact and the temperature of these points reaches the value which Slepian[6] has shown to be equal

$$T = \frac{E^2}{33.5kp} \tag{3}$$

where k is the thermal conductivity of the contact material (calories/centimeters squared/degrees centigrade/centimeters) and p is the electrical resistivity of the contact material (ohms/centimeters cubed). Copper contacts interrupting a one-volt circuit reach a temperature of approximately 4,000 degrees. Obviously, there is no metallic contact material available which will not melt and vaporize at the voltage to be used. Arcing at the contacts is supported chiefly by thermionic emission from the hot points and by thermal ionization of the hot vapor emitted from the points. Arcing can be kept at a minimum by using contact material which evolves a minimum amount of vapor. Tungsten makes an ideal contact because of its high work function, high melting point, low vapor pressure even in the molten state, and high resistance when hot. The current due to arcing at the tungsten contacts is negligible compared with that due to re-establishment of the glow discharge. Therefore, the transient voltage is practically equal the voltage across the glow discharge corresponding to the instantaneous value of current through the circuit.

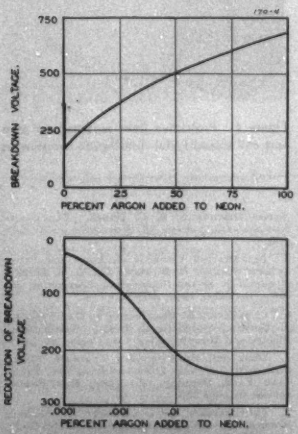

Figure 4. Minimum breakdown voltage for neon with respect to the percentage of added argon (Penning)

Rearrangement of equation 1 shows that the voltage across the glow discharge is equal

$$E = E_0 + (J - J_0)^{1/2} \frac{K}{P} \tag{4}$$

where

$$J = \frac{i}{A} \tag{5}$$

Equation 4 shows that the transient voltage can be made high by the use of low gas pressure. It has already been shown that the pressure must be high if the contacts are to close quickly. A compromise must be made. The pressure should be made only as high as is necessary for the contacts to close in a reasonable length of time; say, one or two seconds. Even so, the transient voltage is not always high enough to insure reliable starting of the lamp. Since E_0 and J_0 have already been fixed, the only other expedient is to increase the value of J.

Equation 5 shows that J can be made large by reducing the value of A. Fortunately, as has already been shown, A, the surface area of the cathode for the glow discharge, should be small to permit quick closing of the contacts. With the bimetal as small as is practical from the standpoint of manufacture, its surface area is still too large to insure reliable starting of the lamp. It is necessary further to increase the value of J by using only one strip of bimetal and letting the other electrode for the glow discharge consist of only a short lead wire with a contact welded to it. The surface area of this short lead wire and contact can easily be made very small. Of course, the highest transient voltage is produced only if at the instant the contacts separate, the current is flowing in the direction that will cause the small surface area electrode to serve as cathode for the glow discharge. The fact that there is only a 50 per cent probability that the highest transient voltage will be produced is not considered objectionable because, if the voltage is insufficient to start the lamp, the energy stored in the series inductance is instantly dissipated in the glow switch, and the contacts immediately reclose to repeat the cycle. The value of the series inductance has little effect upon the magnitude of the transient voltage but does affect its duration. Equations 4 and 5 are only approximately true[7] because the transient voltage varies too rapidly for the glow discharge to reach equilibrium. However, they show what steps must be taken to improve the characteristics of the switch.

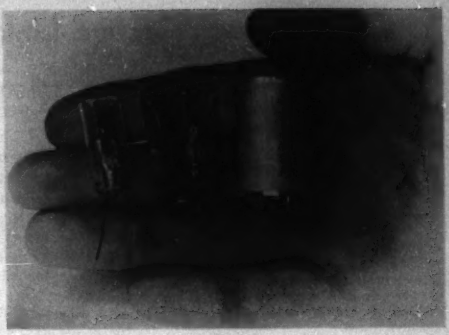

Figure 5. The glow-switch, assembly of glow-switch and capacitor for suppressing radio interference, and the complete starter unit

Conclusion

It has been shown that for proper operating characteristics, the glow-switch necessarily must be small. The small size and simple construction of the switch as shown in figure 5 lend it to economical production on automatic machinery.

A glow-switch will start a lamp under normal conditions approximately a mil-

The Protective Link

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Synopsis: The protective link is a device recently developed for internal mounting in transformer of a wide variety of types and ratings. Its most common application, however, is in distribution transformers where it serves to disconnect the transformer in case of internal fault. Its action in arc extinction depends on a number of factors including a novel arrangement of the lower terminal which allows it to be expelled from the link when heavy currents are interrupted.

Although simple and compact, the link is a very efficient arc-quenching device, and has a remarkably high-circuit interrupting capacity combined with high speed of operation. Power arcs of more than 250,000-kva single phase have been interrupted in one-half cycle.

Introduction

SOME form of circuit-opening means has been used with transformers from the very beginning of the a-c system for the purpose of protecting the line or system against an extended outage in case of damage to an individual transformer. Economic factors in general have dictated the kind or type or the extent of the protection. Large important substations are protected with circuit breakers and differential-transformer protection to remove quickly a faulted transformer. Less important substations are protected by circuit breakers actuated by overcurrent or ground relays, and finally where circuit breakers cannot be justified from the standpoint of cost, high-voltage fuses are used to protect smaller substations, transformer banks, and individual transformers. Recently protective links have been applied to transformers for a similar purpose. They have been used on a wide range of ratings, but it is in the distribution range where they have found most of their application up to the present time.

In this application they are used in conjunction with circuit breakers to permit loading the transformer to its maximum safe copper temperature regardless of the amount or duration of load. The link alone, though designed for long-time lag, will not serve this purpose, because of the extremely long time constant of the transformer. The circuit breaker, on the low voltage side, follows this characteristic of the transformer and effectively prevents it from burnout because of overload. The protective link, on the high voltage side, protects the line from outage which might occur in case of failure within the transformer. In this function, its construction and mounting provide a number of inherent advantages. It is electrically protected against false operation by the transformer breaker on the one side and by sectionalizing or line breakers on the other. It is mechanically strong, and resistant to the action of transformer oil. Because of its internal mounting it is not exposed to weathering, and because of its electrical connection at the transformer bushing it is not subjected to lightning surges. These factors are especially important on the smaller ratings where the physical size of the fusible element is necessarily very small.

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Description of the Protective Link

The appearance of the link as used in distribution transformers is shown in figure 1. This shows a core and coil assembly with a protective link mounted at each side of the porcelain tap-changer block. When assembled in the transformer, the high-voltage bushing lead runs directly to the top terminal on the link, thus placing the link electrically ahead of any fault which may occur either in the coil or the tap changer. The link itself is shown in section in the drawing of figure 2. It is simple in construction, consisting essentially of a fusible element enclosed in an insulating tube with a fixed and a movable terminal. The movable terminal, mounted at the

Figure 1. Protective links mounted on core and coil assembly for distribution transformers

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lion times, so that its life ordinarily should be very long. However, when a lamp fails, the switch keeps operating in an attempt to start it. Under failed lamp conditions, the life of the switch is approximately 100 hours.

In addition to starting lamps under conditions which insure good lamp life, the glow-switch has a number of advantages over other types of starters. It is operative over a wide range of current and compared with other types of lamp starters, it has a very long life under failed lamp conditions. Because the glow-switch is a two-wire device, it reduces wiring to a minimum. Simplified wiring permits placement of the glow-switch in a removable capsule which fits into an extension of the fluorescent lamp socket. Field results with the glow-switch, since its introduction two years ago, have been very satisfactory, and at present there are approximately six million glow-switches in use.

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lower end of the tube, is one of the new features of this design, and plays an important part in extinguishing the arc, as explained below. The fusible element consists of a mechanically strong wire which is chemically neutral in transformer oil and resistant to corrosion; these properties are essential to insure stability of the fusing characteristic over a long period of time. The fusible element is composed of copper, or, for the smaller size, a high-resistance copper alloy. The fusing temperature is much in excess of the boiling temperature of the oil. This is an important characteristic, for it tends to reduce the damage to the link caused by momentary overcurrent, and provides a means for control of the fusing-time curve of the link as described below.

Surrounding the fusible element (figure

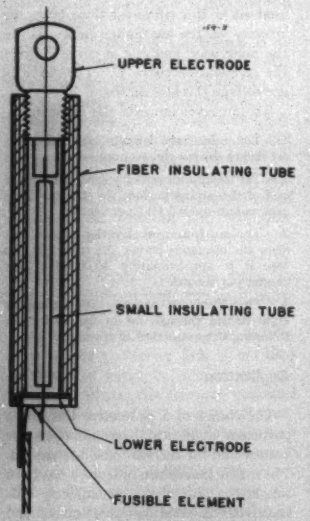

Figure 2. Section through protective link

2) is a small insulating tube, the purpose of which is to retard the flow of heat from the wire. When a current slightly above the minimum fusing value is passed through the wire, its temperature is increased depending upon the rate of heat generation in the conductor and the rate of heat dissipation into the oil. With the current constant, the temperature increases approximately exponentially until the boiling temperature of the oil is reached. The chemical change in the oil under these conditions greatly increases the rate of heat dissipation of the

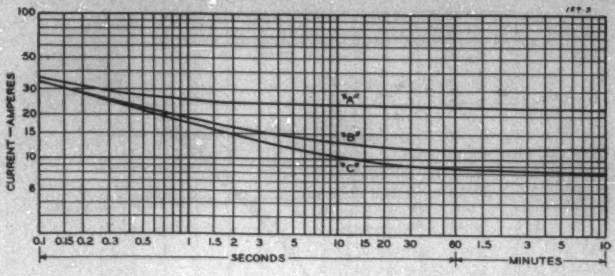

Figure 3. Fusing characteristic of protective links

(a)—Bare conductor in oil
(b)—Small insulated tube over conductor
(c)—Small insulated tube over conductor and gas entrapped within link

oil. As a result, little further change in temperature results until the distillation gases sufficiently blanket the conductor. The temperature again increases approximately exponentially until the fusing point is reached.

If a bare conductor placed in the oil were to be used as a protective link, the gases distilled from the oil would escape freely and the current-time fusing characteristic of the conductor would be quite flat as shown in curve *A*, figure 3. By surrounding the link with a small insulating tube, the distillation gases quickly displace the oil in the tube and it then effectively insulates the conductor and retards the heat flow. This reduces the current and the time required to fuse the conductor for all ranges of current and time beyond that where all heat is stored in the conductor. An example of the reduction in current is shown in curve *B*, figure 3. By controlling the blanketing action of the distillation gases, the shape of the current-time curve can be adjusted to the desired shape to co-ordinate most effectively with other current-limiting devices on the system. The maximum blanketing occurs when the conductor is entirely surrounded by a gas (curve *C*, figure 3).

With the present knowledge of the impulse characteristics of transformer insulation and with modern lightning protective devices arranged for balanced lightning protection, major insulation failures from lightning have been practically eliminated. Therefore, line-to-line or line-to-ground failures of transformers in service, which would make it necessary for the protective links to open the full short-circuit current of the system, are uncommon. To insure successful operation, however, the protective links should be selected with sufficient arc-interrupting capacity to interrupt the current resulting from a short circuit across the terminal board of the transformers.

This, as mentioned, is not the usual condition. One of the most usual causes of transformer failure is short circuit in one of the windings between turns or between coils. Under these conditions, the fault current builds up spasmodically with a rush of current as each new element of the winding is involved in the failure. Since a considerable portion of the trans-

Figure 4. Oscillogram of protective link operation showing

(a)—Voltage across link
(b)—Current through link
(c)—Timing wave
(d)—Position indicator wave

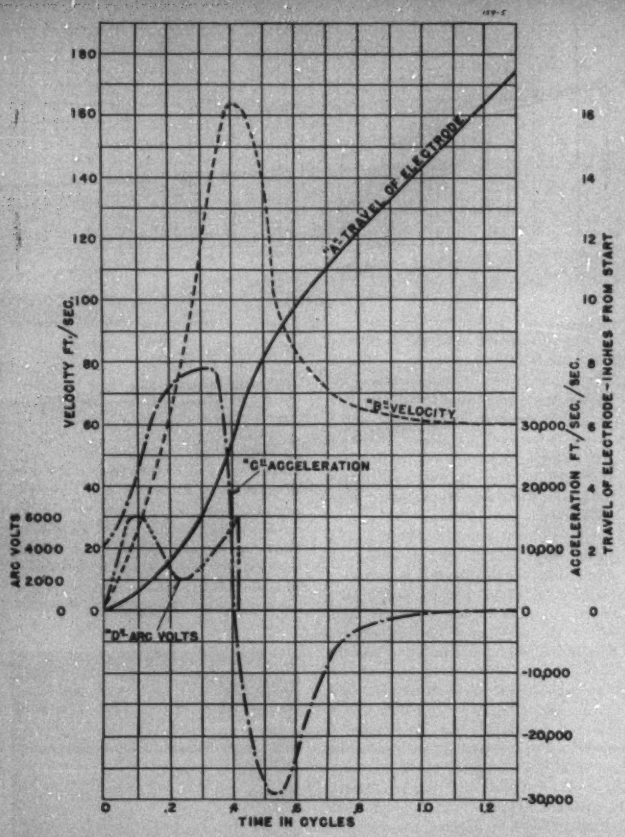

Figure 5. Analysis of electrode travel during arc interruption

former-winding impedance remains in series with the fault, the current builds up to a value sufficient to blow the protective link but does not approach system short-circuit proportions.

At the time of trouble in actual service, when the current reaches a value sufficient to fuse the link, an arc is formed in the oil inside the fiber-insulating tube. A high pressure is immediately developed inside the tube which increases the arc-voltage drop and aids in quenching the arc. This high pressure drives the lower electrode violently from the tube as if by explosive action. The arc trailing after it passes from the high-pressure area inside the tube to an area of comparatively low pressure outside the tube. This is an area of violent turbulence which is effective in arc quenching, principally because of the diffusion of the oil into the gas bubble surrounding the arc. Finally, the movable electrode moves rapidly through the oil stream tending to "neck" the arc and quench it.

Interruption of fault current occurs usually at the first current zero after the arc has been struck. The rapid movement of the free terminal through the oil builds up a layer of fresh oil between the moving electrode and the gas bubble after current zero, which effectively prevents restriking. Mounting the link in a vertical position so that the free electrode moves downward aids in this respect since the gas bubble is displaced upward by the pressure of the oil.

In order to investigate the action which takes place during the operation of the protective link, a special test was set up. A link was made in which the lower electrode was carried on a light but rigid arm. This arm was pivoted at one end, to allow the electrode to swing down freely as it does when attached to a flexible cable. A commutator device was mounted on the arm to permit recording of its position on an oscillograph.

The action of the link in interrupting the arc and a conception of the speed and the forces involved can be obtained from the results of this test as shown in figures 4 and 5. Figure 4 is an oscillogram of an interruption of a circuit connected for 1,500 amperes and 22,000 volts. It shows the normal operation of clearing the circuit in one-half cycle, and also shows very clearly the eight make-and-break points obtained by the commutator (curve *D*, figure 4).

From these data, a curve of position of the electrode against time is obtained, as shown in figure 5, curve *A*. Graphical analysis of this curve for slope gives the velocity of the electrode, curve *B*. In the same way, analysis of curve *B* gives the acceleration curve *C*. The curve of arc voltage *D* is also shown.

These curves indicate the following:

1. The electrode travels approximately six inches during the arcing period.
2. The maximum velocity is reached at the end of the arcing period; in this case it is approximately 165 feet per second.
3. The maximum acceleration occurs just after the electrode leaves the tube; in this case it is approximately 40,000 feet per second per second.
4. The electrode travels approximately eight inches through oil in the half cycle following the extinction of the arc.

Application

The choice of a protective link for a particular application depends upon the voltage and the current to be interrupted. The simple link shown in figure 1 has been supplied extensively to a completely self-protected distribution transformer, and other distribution transformers exposed to severe lightning conditions. Its interrupting ability is adequate for practically all applications for transformers up to 100 kva and 15,000 volts. These links will interrupt successfully 12,000 to 20,000-kva single phase in the above voltage range.

For larger units in the range of approximately 20,000 to 75,000-kva single-phase interrupting capacity, a longer and stronger fiber tube is necessary. A protective link of this type is shown in figure 6. The general construction remains the same. It will be noted, however, that the lower electrode is not attached to the tube, but is suspended from the fixed

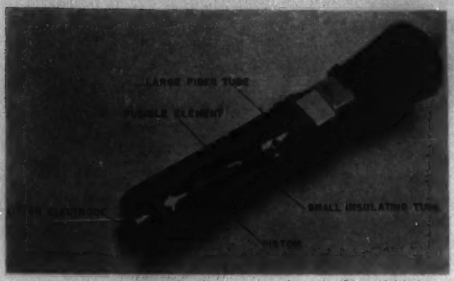

Figure 6. Protective link for application to power transformer

electrode. A piston of insulating material is used to transmit the mechanical impulse to the movable electrode. Protective links of this rating have been applied to completely self-protected power transformers in sizes up to 3,000 kva and 33,000 volts.

Another interesting application is to subway distribution transformers. Links with an arc-interrupting capacity of 10,000 amperes were applied to 2,400-volt subway transformers. These transformers were equipped with thermally-operated breakers in the secondary, properly coordinated with the protective links and arranged to protect the units against burnout from overload and secondary short circuit. The use of the protective links together with a disconnecting-type, high-voltage cable connection made the unit self-contained and very easy to install.

For application to still higher capacity circuits, the protective link is modified as shown in figure 7. Means are provided to reduce the pressure produced inside the tube and to increase the arc-quenching action at low currents and high voltages. The reduction in pressure is accomplished by enlarging the space above the main insulating tube and mounting inside it a shock-absorbing device. This device consists of a thin-walled cylindrical ring filled with gas under atmospheric pressure. Under high-current operation, the walls of the gas container collapse and cushion the pressure wave, thereby reducing the mechanical shock and the internal pressure in the device.

Interruption of low currents at high voltage is accomplished by means of the small auxiliary fiber tube. This tube creates a high-pressure zone immediately surrounding the arc, making it effective for currents as low as the exciting current of the transformer. At high current this tube is ruptured.

Links of the type as shown in figure 7 are applied to transformers with voltage ratings up to 69,000 volts. They have been tested at power levels of more than 250,000-kva single phase. An example of this is shown on the oscillogram of figure 8.

Field Experience

Within the last few years many thousands of protective links have been placed in service in distribution transformers. Some of these have had occasion to operate either because of a defect in the winding causing coil failure, or because of low electrical clearance at some point causing breakdown on surge. In most cases the lower electrode was driven from the end of the tube. Occasionally, when the current was only slightly above the minimum required to fuse, the arc was quenched before the electrode was dislodged. Usually the electrode was found to be driven out violently; in fact the evidence of the violence of this action is some indication of the magnitude of the current interrupted. But even when severe mechanical damage was done, the link served to clear the circuit, and the small amount of burning on the electrodes showed that the arc was extinguished quickly.

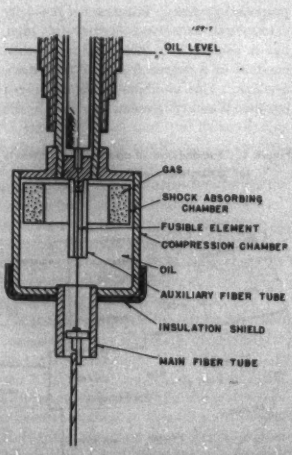

Figure 7. Protective link for high-current and high-voltage interrupting capacity

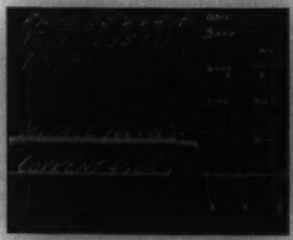

Figure 8. Oscillogram of protective link operation for link shown in figure 7

A case of operation on power transformer has occurred. Links were applied to the high-voltage side of a 33,000 to 4,160 volt, 1,000-kva 3-phase unit, and a breaker was connected on the low-voltage side. This breaker was rated at 5 kv, and protected by 33-kv links connected in series. This was considered desirable because high- and low-voltage lines were carried on the same pole. Shortly after this unit was put into operation, a wind storm blew off a sheet metal roof from a barn which struck the line, broke the high-voltage wires and caused them to fall across the low-voltage line. The breaker opened, but was not able to clear the high-voltage arc, which burned across the open contacts until the protective links cleared the circuit. Two of the links on the low-voltage side and one on the high-voltage side were blown during this disturbance. Except for the burning of the breaker contacts and adjacent parts, no damage was done to the unit. After reloading the links, the transformer was put back on the line and has since functioned satisfactorily.

Variations of Atmospheric Temperature With Altitude in the United States

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IT has long been recognized that with increase in altitude the density of air decreases and influences the voltage rating and temperature rise of electrical apparatus. However, different standards for apparatus do not give the same weight to these factors. Examination of Weather Bureau data shows that there is a decrease in average atmospheric temperature with altitude, which should compensate to some extent for the influence of the decrease in air density on the rate of cooling at higher altitudes. This led to a study of temperature records of the United States for the purpose of presenting a summary of the variation of mean temperature with altitude.

The Weather Bureau of the United States is to be complimented on the fund of data which it has collected and the usable form in which it is available. The chief source of data used in this paper is the 1938 issue of Climatological Data for the United States.[1] In this issue there are temperature data from 3,119 stations for the year 1938 and the departure of the annual mean temperature from the mean of the temperature for all years of record. Consequently, by algebraic subtraction of the departure of the mean for 1938 from the annual mean, the mean temperature for the period of record is obtained.

The daily maximum and minimum temperatures are read from properly exposed thermometers at the co-operative observation station. At the first-order Weather Bureau stations thermograph charts are taken, giving continuous record of temperature variations. The records made by co-operative observers of the Weather Bureau, which are used largely in preparing charts and drafts, are made with standard maximum and minimum thermometers exposed in approved shelters, usually at an elevation of five feet above the ground. The true average daily temperature corresponds closely to the average of 24 hourly observations, but as several other combinations of hourly values give averages that differ but little from the true daily average some one of these is generally used to reduce observational work. The combination—

$$\frac{(7\text{ a.m.}+2\text{ p.m.}+9\text{ p.m.}+9\text{ p.m.})}{4}$$

gives a value which differs only slightly from the true daily average, and

$$\frac{(\text{sunrise}+2\text{ p.m.}+9\text{ p.m.})}{3}$$

also gives fairly accurate results. The formula

$$\frac{(\text{maximum}+\text{minimum})}{2}$$

is easy of application and very satisfactory when dependable maximum and minimum thermometers are used and properly exposed. The mean of the daily extremes is, as a rule, slightly too high, but it usually does not vary more than one-half of a degree from the true daily average. This combination is employed by the Weather Bureau to obtain the average daily temperature, and the data for the accompanying charts and diagrams were compiled by its use.[2]

A superficial analysis of some data indicated that the variation of temperature with altitude at the same general altitude differed with the watershed, as, for example, the eastern and western watersheds of the Allegheny Mountains in Pennsylvania. Therefore, in this analysis the country was divided into six districts as shown on the map, figure 1, as follows:

District No. 2—North Central United States (Mississippi Watershed).

District No. 3—Northern Rocky Mountains and Western Seaboard.

District No. 4—Southern Atlantic Seaboard.

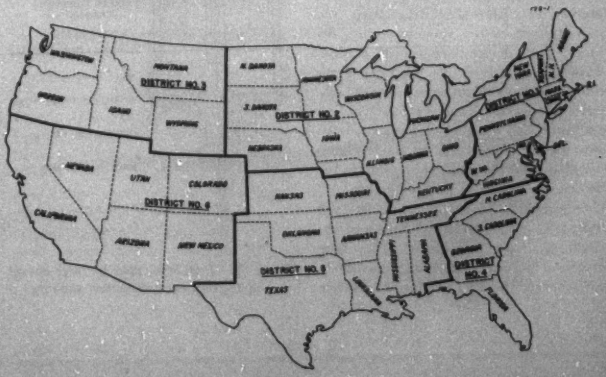
District No. 5—South Central United States (Mississippi Valley).

District No. 6—Southern Rocky Mountains.

In order to simplify the analytical work, the border lines of the districts, in most instances, have followed the border lines of the several states included in each. While this makes for odd-shaped districts, a check on one district in which the northern and southern border lines were made to parallel the lines of latitude showed that the complexion of the results was not materially changed.

The mean variation of temperature with altitude for the entire United States for all years of record for 3,119 Weather Bureau stations, is shown in figure 2. The slope of this curve indicates a decrease in average temperature of approximately one degree for every 330-foot increase in altitude. This curve of temperature with altitude is not a straight line and the increment of elevation per degree of average temperature will vary. In a report from the United States Weather Bureau,[3] it is stated that the

Figure 1. Subdivision of country into districts for temperature-altitude analysis



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The author acknowledges the able assistance of C. S. Hague, Jr., and R. C. Fowler in analyzing the vast amount of Weather Bureau data, which form the basis for the curves presented in this paper.

1. For all numbered references, see list at end of paper.

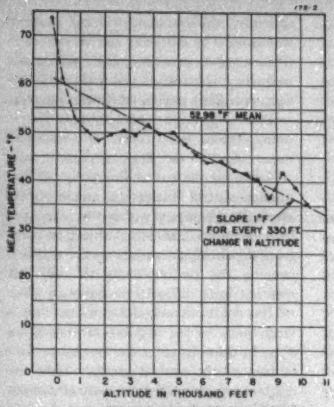

Figure 2. Variation of mean temperature with altitude for the entire United States

(Temperatures are mean for all years of record based on data from U. S. Weather Bureau reports)

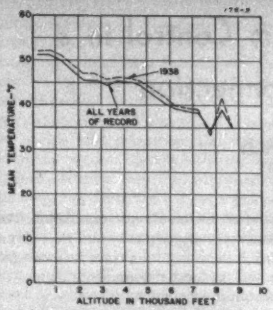

Figure 3. Comparison with altitude of mean temperatures for the year 1938 and mean temperatures for all years of record

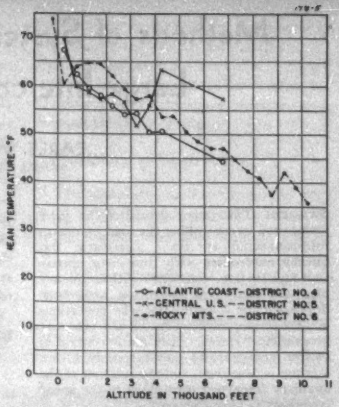
178-5
-o- ATLANTIC COAST - DISTRICT NO. 4
-x- CENTRAL U.S. - - DISTRICT NO. 5
-•- ROCKY MTS. - - - DISTRICT NO. 6
MEAN TEMPERATURE - °F
ALTITUDE IN THOUSAND FEET

Figure 5. Variation of temperature with altitude for the southern districts of the United States

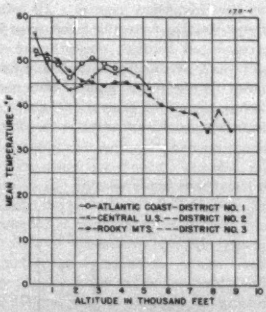
178-4
-o- ATLANTIC COAST - DISTRICT NO. 1
-x- CENTRAL U.S. - - DISTRICT NO. 2
-•- ROCKY MTS. - - - DISTRICT NO. 3
MEAN TEMPERATURE - °F
ALTITUDE IN THOUSAND FEET

Figure 4. Variation of mean temperature with altitude for the northern districts of the United States

average decrease in temperature with increase in altitude in free air is about one degree for each 330 feet, but the rate varies with the season of the year and also is much affected by local conditions. It is more rapid in summer than in winter and is greatest during the warmer hours of the day. A study made of temperature variation with altitude made in England,[3,4] determined by sounding balloons, showed a decrease in temperature of one degree Fahrenheit for every 300-foot increase in altitude up to approximately seven miles, beyond which there is no further reduction in temperature.

The length of time records have been kept at the individual observation stations varies from 2 to 150 years. Through the use of mean temperatures for varying lengths of time the influence of periodic changes of temperature may be introduced. A method of extending short-term records has been suggested for the purpose of developing a satisfactory comparison between prevailing temperatures of two stations.[4] This may be done by comparing the mean temperature at the short-term station with the mean for a similar period of a similarly located long-term station and assuming that the same relationship would exist between the long-term means of the two stations. This procedure was not followed out in this paper, because it would multiply the analytical work tremendously and the increase of accuracy that might be expected would not warrant it. This is demonstrated in figure 3, which shows two curves of variation of temperature with altitude. One is the mean temperature for the year 1938 and the other is the mean temperature of all years of record. The year 1938 was a warm year and the annual mean temperatures for the entire country were above normal. However, in comparing the mean temperatures of one year with the mean temperatures for all years of record, it is seen that the curves are similar in shape and the difference between them is not great.

Figure 4 shows the variation of mean temperature for all years of record for the three northern districts numbers 1, 2, and 3, of the United States, and in figure 5 the same curves for the three southern districts numbers 4, 5, and 6 are shown. In order to interpret these clearly a brief description of how the data were worked up will be helpful. The mean temperatures for all years of record for all Weather Bureau stations were first calculated from the annual mean of 1938 and the deviation of this mean from the mean of all years of record.[1] It was then arbitrarily decided that the temperature data would be analyzed on the basis of 500-foot increments in change of altitude. The mean temperature of all stations located at altitudes between 0 and 500 feet, 501 and 1,000 feet, etc., were averaged and plotted halfway between the 0 and 500, 501 and 1,000, etc., ordinates on the curves. Analysis of the districts, using smaller increments for altitude, may influence the shape of the curve slightly, but will not seriously affect the general considerations involved.

Referring to figure 4, it is seen that the temperature decreases quite rapidly from 0–2,000 feet. There is then a reversal in the slope of the curve and the temperature increases gradually up to 3,000 or 3,500 feet. The mean temperature again falls off with increased altitude, but at a slower rate than in the first part of the curve. The curve of the Northern Rocky Mountain district seems to become erratic at the high altitudes. This is probably explained by the fact that there is only one Weather Bureau station in the ranges of altitude of 7,500–8,000 and 8,000–8,500 and only two in the range of 8,500 to 9,000. In ranges where only one or two stations are located unusual local conditions are not averaged out. This is shown even more clearly in figure 5 in the curve for South Central United States for the ranges of altitude of 4,000–4,500 feet and 6,500–7,000 feet. These points are also for only one Weather Bureau station. The data for the point in the 4,000–4,500 range were taken at Alpine, Texas, and extend over a period of 16 years. Therefore, any extreme annual

Methods of System Control in a Large Interconnection

EARLE WILD
MEMBER AIEE

Synopsis: This paper describes the principles used in controlling the load in a large interconnected system. Automatic frequency controllers with time-error correction and tie-line controllers with frequency bias and time-error correction have been developed for co-ordinating the operations of interconnected systems of any size and geographical extent. Automatic control of two or more stations simultaneously within a group is described, and the relation of the auxiliary frequency controllers to the speed governors is also discussed.

Introduction

THE interconnection of many contiguous power systems into large coordinated groups of several million kilowatts has made imperative the development of control apparatus of great variety and refinement. The intended purpose of these interconnections required that economies of generation be maintained and that designated power flows be held steady. The geographical extent and the variety of relationships between the many properties made it necessary to use control equipment which would function in widely separated locations and with a minimum of direction. Increases in the size and number of large variable loads indicated the need for closer speed control. The final object of the control apparatus, therefore, was to maintain the most constant frequency and thus permit each local group to operate its individual system as local requirements dictate for maximum economy.

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EARLE WILD is load dispatcher for the Commonwealth Edison Company, Chicago, Ill.

Basic System of Control

The original system of control consisted in giving one central group responsibility for the frequency control. All other groups starting from this point were interconnected through one or more tie lines which were held at definite scheduled loads. These other groups thus were varying their own generation locally, to meet their own load requirements. Theoretically, the frequency-control stations would only be following the variations in the load of the central group. Automatic frequency controllers and automatic tie-line controllers were used for this purpose.

Two objections arose to this simple plan. When two, three, or sometimes more of the tie lines departed from schedule in the same direction, the frequency-control station was unable to restore the frequency without an excessive load change. The other objection came from the continual variations in frequency causing the tie-line loads to vary. It was not only difficult to maintain these tie-line loads at scheduled value, but a large part of the regulation was being done in opposition to the frequency correction of the central group. Thus the original simple system of control did not function as well as intended.

Tie Line Biased by Frequency

These difficulties led to the development of the tie-line biased-by-frequency method of automatic control, which is

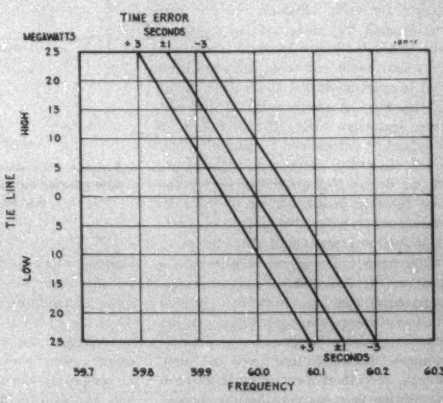

Figure 1. Characteristic curves of a tie-line controller

Shows tie-line load departures from normal, for corresponding frequency and time-error deviations

condition should be fairly well averaged out. The displacement can only be explained by unusual local conditions. On the other hand, the point in the 6,500–7,000-foot range is for the Weather Bureau Station at Mount Locke, where the period of record is only four years. Here a year of unusual temperature conditions might have affected the mean temperature some but probably not sufficiently to bring this point within the more or less expected trend of the curve.

Examination of figure 5 shows changes in slope at different points along the three curves, but these do not appear in the same range of altitudes as was the case with the three northern districts. As would be expected, the mean temperatures at the lower altitudes are higher than for similar altitudes in the northern districts. However, the curves for the northern and southern districts approach each other at the higher altitudes.

As seen from figure 2 the retardation and inversion of the temperature-lapse rate supports the general practice of making no correction for ratings for altitudes up to 3,300 feet (1,000 meters). Data are presented here from which a basic study may be made to determine the limits at which standard apparatus may be used at higher altitudes.

References

1. Climatological Data of the United States for 1938 from the United States Weather Bureau, Department of Commerce, Washington, D. C.

2. ATLAS OF AMERICAN AGRICULTURE, Part 2, Climate, Section B, Temperature, Sunshine and Wind, Joseph B. Kincer, senior meteorologist, United States Weather Bureau, Department of Commerce Washington, D. C.

3. SIR JOHN MOORE'S METEOROLOGY (book).

4. ELEMENTS OF HYDROLOGY (book), A. F. Meyer.

being used extensively in large interconnections. With it, the fundamental plan of regional control of loads is continued, but instead of holding tie-line loads at constant value, they are permitted to deviate from schedule whenever the frequency varies and in a direction to relieve the burden of the frequency-controlling center. The amount the tie-line load is varied, commonly known as *bias*, is a function of the frequency effect on load and the action of the speed governors of the turbines. This relationship will be described in a later section.

This bias principle permits tie-line loads to be varied in a relieving direction and be restored with a minimum change in generation in each group. It also assures the frequency-regulating center that several tie lines will be biased correctly for each one causing a frequency departure from normal. Thus any number of groups may be interconnected under this plan without increasing the burden of the central group.

The performance on several of these tie lines has been checked by means of counters, which register the deviations from normal. These show that most groups hold to scheduled tie-line loads about 70 per cent of the time, cause frequency deviations about 10 per cent of the time, and vary in a direction to relieve the frequency deviations 20 per cent of the time. Actually, each group on bias is assisting, in direction at least, twice as much as it is contributing to frequency deviations.

Frequency Effect on Load

Before the correct amount of bias could be determined for any system it was necessary to know the effect of frequency changes on the load. Studies were made in the Chicago system to determine the amount of load change for a given frequency change. It was found, as a very general rule, that one-tenth-cycle frequency departure resulted in approximately a one per cent change in system load. This figure is somewhat less than has been observed on some large interconnections, but has been checked many times since the staged tests were made, whenever important intersystem tie lines opened automatically under heavy load and there were sudden frequency changes. This figure takes into account the average response of a composite group of governors on the turbines affected, as they are found in normal service and without unusual attention being given to increasing their sensitivity or to block them.

This figure also includes some effect of voltage changes. Whenever the frequency departs from normal there is a change in voltage, due to change in the speed of the shaft-driven exciters on the main turbines. A test in one large load zone, which is mostly industrial in character, shows that whenever the voltage drops one per cent there is a $1^1/_2$ per cent drop in customer load. However, when the frequency drops there is not a general drop in voltage proportional to the drop in speed, as the automatic voltage regulators provide correction for at least 50 per cent of the load. Probably the largest effect of minor frequency changes comes both from a change in speed in the industrial motor load and the action of the more sensitive speed governors.

Tie-Line Bias Setting

The tie-line bias setting used is the one which will permit the tie-line load to change an amount equal to the group-load change for any given frequency deviation. As the frequency rises the load increases, but the generation remains constant except for the small decrease caused by the speed governors. The tie line supplies the difference and thus tends to oppose the frequency rise. When the frequency is restored to normal the tie-line load is returned to schedule without adjusting the generation. Thus whenever the frequency varies one-tenth cycle, the tie-line load is changed an amount equal to one per cent of the total generated load. This bias is extended proportionally for other departures from the normal of 60 cycles.

Time-Error Bias

There are times, however, after the frequency has departed from normal for a considerable period, when it is necessary to arbitrarily offset the frequency in the opposite direction in order to correct an integrated frequency or time error. If a great many of the tie lines in an interconnection are being operated on the tie-line bias principle, it becomes very difficult for the centrally-located frequency-control station to offset the frequency manually. It was desirable, therefore, to add time-error bias to each of the frequency-biased tie lines. Whenever the time departs from normal a time-error indicator, therefore, similarly causes a departure in tie line in such a direction as to offset the frequency and correct the time error.

Figure 1 is a chart of the relation of tie-line load to frequency and electric time error in a controller. All three of these factors must be satisfied, or the controller will change the system load until the tie-line load reaches a balance point. Figure 2 shows the changes in tie-line load as the frequency and time-error deviate from normal on a large group.

Description of Controllers

The equipment used in the control consists of the following apparatus:

1. Frequency controller with an electric time-error correction.
2. Tie-line controller.
3. Tie-line controller biased by frequency.
4. Tie-line controller biased by frequency and with electric time-error correction.
5. Cascading settings of tie-line controllers when used in series.
6. Devices for controlling the load on two turbines in separate stations.

The tie-line controller biased by frequency and with electric time-error correction, and the frequency controller with electric time-error correction will be described. Figure 3 shows a diagram of the electrical circuit of a typical tie-line controller, which has both frequency bias and time-error correction. The apparatus, as commonly used for this purpose, consists of a frequency bridge which is tuned for 60 cycles. One corner of the bridge has been opened and extended to a slide wire mounted in the recording tie-line meter. The zero or center point of this slide wire has a front "setter" and is placed at the scheduled tie-line point, wherever that may be from hour to hour. The movable contact of this slide wire is operated by the tie-line recorder carriage. Whenever the tie line is at the scheduled point, the contact is in the center of the slide wire and the frequency bridge remains balanced. If the tie line is displaced to one side or the other of the zero point, more resistance is inserted in one leg of the frequency bridge than the other, calling for a change in frequency in order to restore the balance of the galvanometer circuit or the correction of the tie-line load. Similarly, a second corner of the frequency bridge has been opened and extended to a slide wire in a time-error indicator. This time-error indicator consists of two electric motors, one driven by the system frequency and the other driven by the exact frequency of 60 cycles obtained from a crystal oscillator time standard. The speed of these two motors is compared through differential gearing, and any resulting displacement operates the pointer on the slide wire of the time-error indicator to change appropriately the balance point on the frequency bridge.

In order to regulate a system within plus or minus one second over widely scattered controllers requires that highly accurate time standards be provided. Some of the larger cities have sources of astronomical time, but these are not generally available over a wide interconnection. It has been agreed, in this interconnection, to use the primary frequency standard of the crystal oscillator type as a source of true time. These have an error of one part in two million and may be readily compared with observatory time as received from Arlington. Even assuming an error in setting these oscillators at widely scattered points, it will not be difficult to keep the time-error indicators within a quarter of a second of each other. The amount of tie-line departure that might be introduced by an error of a quarter of a second in the time standard would, at the most, be only one or two megawatts in any group.

The apparatus in the frequency-controlling centers is similar to the tie-line controlling apparatus described above, except that there is no tie-line slide wire. The bridge is continuously tuned for 60 cycles, except when the time-error indicator is displaced from its center point.

The galvanometer is a Leeds and Northrup contact-making type, in which there are wiping cams which make contact with the "raise" or "lower" circuits once every two seconds. The duration of these contacts is proportional to the amount the frequency has deviated from the calibration value of the frequency bridge.

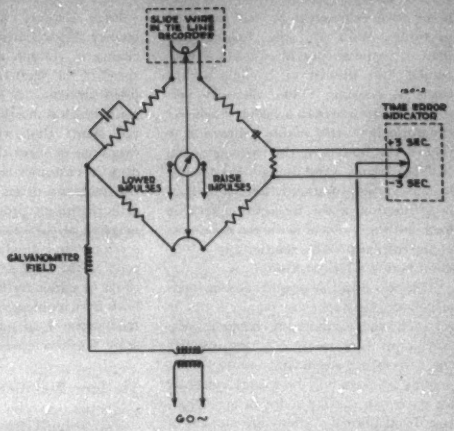

Figure 3. Circuit diagram of a tie-line controller, with frequency bias and time-error correction

Rate of Load Response

The galvanometer circuit is unbalanced any time one of the three characteristics is varied from the normal value. If two of the characteristics are abnormal, the galvanometer is still further unbalanced unless these two are in opposition.

Comparison of these counterinfluences in the frequency bridge is very important. For example, if the tie line is off schedule and the frequency has not departed from normal, indicating that the load in some other group of companies is off schedule in the opposite direction, the controller sends out very short corrective impulses and it takes considerable time for this tie-line error to be corrected. Similarly, the other zone, whose generation is displaced from the correct value in the opposite direction, would be making a very slow correction and the load of the frequency-controlling center would not need to be disturbed. If, on the other hand, were the tie line to be off schedule in the same direction as the frequency, indicating that this group of companies is producing the frequency departure, the controller would send out very long impulses and cause the generation to change very rapidly at the point which was most responsible for the frequency departure.

The unbalancing of the bridge by time error is a much more gradual influence and requires, likewise, a much longer period for the time correction.

The controllers in the large group have been set to give a maximum correction to tie-line load of 20 megawatts in 30 seconds. The frequency-controller group has about one-half this rate of response, and the smaller groups are decreased to one megawatt a minute.

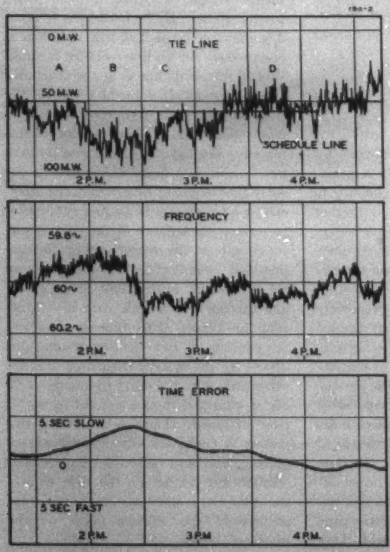

Figure 2. A tie-line load curve showing variations from schedule, effected by frequency and time-error biases

The tie-line load is (*A*) high with low frequency, (*B*) increasing with slow time error, (*C*) decreasing with high frequency but continued time error, (*D*) low with high frequency

Cascading of Controllers

Several controllers may be installed in series along an extended transmission link, as shown in figure 4. The one most remote from the frequency-control center is given a bias setting proportional to the

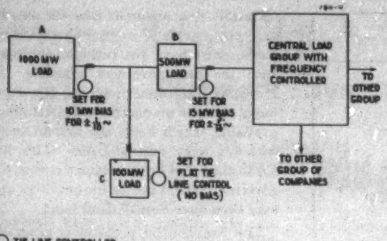
A
1000 MW LOAD
SET FOR 10 MW BIAS FOR ± 1/6 ~
B
500MW LOAD
SET FOR 15 MW BIAS FOR ± 1/4 ~
CENTRAL LOAD GROUP WITH FREQUENCY CONTROLLER
TO OTHER GROUP
C
100MW LOAD
SET FOR FLAT TIE LINE CONTROL (NO BIAS)
TO OTHER GROUP OF COMPANIES
TIE LINE CONTROLLER

Figure 4. Cascaded settings of three tie-line controllers on a transmission system

Bias setting of group *B* includes bias of group *A*, but does not include group *C*, a small system operating on flat tie-line control

size of its system. The next controller toward the frequency-controlling center is given a setting which includes its own proportional bias and the bias of the controller in back of it. If there are controllers in smaller companies which are on flat tie-line settings or which are held manually at a constant value, these, of course, are not taken into account in determining the bias setting. The controller which is nearest to the frequency-controlling center and having the highest bias may actually be operating in one of the smaller companies or one of the smaller generating stations. If the controller in the more remote company should fail to effect its tie-line departure, the controller more centrally located would then be called on for a contribution out of proportion to the size of the latter company. This is prevented in two ways: (1) By a suitable load-limiting band on the generators which restrict the departure to a proper value, and (2) by limiting the rate of response of the smaller controller so that the larger company will have sufficient time in which to make its correction before the smaller company has made an extended departure from its normal generation.

In one large interconnected system there are now 60 companies operating in parallel. These have generally adopted this principle of frequency and tie-line control. There are 17 of these controllers operating in parallel, 2 of them regulating the frequency only, and the other 15 on one or another form of tie-line control. The smaller companies are generally on flat tie-line control unless they are in series with a larger group which is on bias. One has installed time-error correction, and several others are now providing time-error correction equipment. With this method of control all local problems of generation are handled locally. Responsibility for frequency departures or inadequate generation is indicated at its source and corrected. The physical distance between companies or groups of companies is not a limitation, and new groups may be added to the interconnection and perform satisfactorily by adding a new controller without requiring changes in any of the existing facilities.

New interchange contracts which are made locally between any groups of companies do not call for changes in the apparatus, as it is adaptable to almost any power-flow requirements. The only precaution necessary is that the frequency bridges must be reasonably accurately tuned for 60 cycles. Where time standards are provided this is very simply checked, and where there are no standards, other apparatus, such as tuning forks, can be used, which will permit checking the frequency bridge accurately enough for load-control purposes.

Simultaneous Automatic Control of Two Stations

Once a company or group of companies have installed a controller, the problem arises as to the method to be used in utilizing the controlling impulses. The load and the number of generating stations have frequently grown to a point where it is not practical to assign the regulating responsibility to one station. This has been overcome in the Chicago area by the installation of one controller, which is sending its correcting impulses to two generating stations simultaneously. This appears to be the best arrangement in any company or group of companies which are operating under a pooling arrangement, and the control of the load on the local transmission system is not necessary.

After the controlling impulses are directed to two stations, it is desirable that the turbine selected for the automatic control in each station respond in similar amounts to the identical impulses. These turbines may be of different size and have entirely different governor characteristics. Two devices have been used for introducing these impulses into the governors of the respective turbines. One of these consists of a rheostat which operates a torque motor attached to the pilot cylinder of the governor, and makes a small and controlled load change. The two rheostats may be easily timed to travel at the same rate in the two stations, and by control of the necessary torque they can be made to make similar load changes, except at valve-opening points. These valve-opening points are traversed manually. This device, acting on the pilot valve, is not only faster in response than the synchronizing motor, but it avoids any inertia or loose play which is present in governor linkage. The rheostat also acts as its own load-limiting device.

The other apparatus which has been developed consists of an instantaneous wattmeter of the Kelvin balance or electronic type, in which the small driving motor in the meter is used to drive the carriage of the meter from the impulses of the controller. The impulses are also sent to the synchronizing motor, and if the turbine makes a larger load change than required for the length of impulses being used, the wattmeter becomes unbalanced and interrupts any subsequent impulses

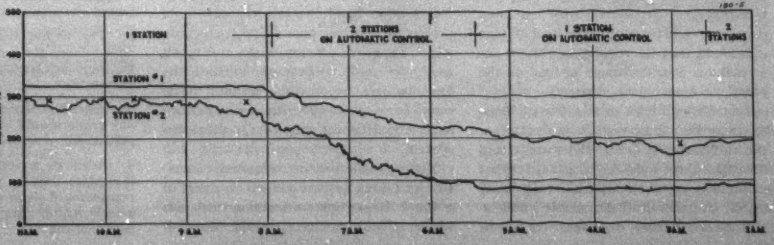

Figure 5. Load curves of two stations equipped for simultaneous automatic control

Amount of load variations at (*X*) increases sharply when only one station is on automatic regulation

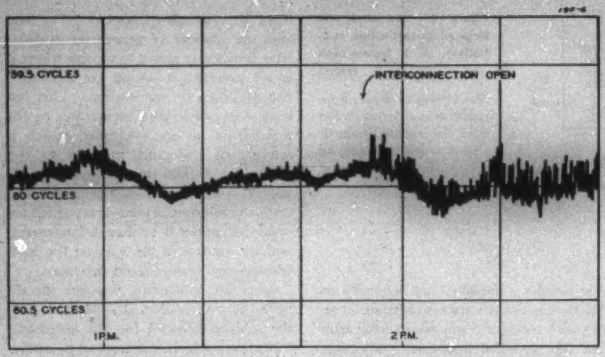

Figure 6. Frequency curve of a large system, showing effect of interconnections on width of frequency variations

to the turbine. The speed of the driving motors in the two wattmeters can similarly be timed together.

Need for More Automatic Control of Stations

In any station which has automatic load control, the variation in its load can be analyzed to come from two sources: One, the variations in the load of the system as it changes from minute to minute, and the other the irregularities in generation of the nonautomatic stations. These latter variations are caused largely by the inability of these stations to follow adequately the system-load changes. Frequently it has been found that some of the largest burden on the automatically-controlled station comes from the simultaneous delayed action on two or three other stations within the same group.

In the Chicago system an attempt was made many years ago to assist all stations in following the load trend by having a system totalizer in every operating gallery, which would indicate the total system load at all times. Each operator was then given a schedule which indicated the portion of the system total load assigned to that station. Although this method has proved quite workable, no operator is able to follow manually the trend as fast as the automatic station does, and so after each large load change it is found that the regulating station has to make a counterchange of load as the other stations follow manually.

In a system of, let us say, five stations, one may be a base-load station, another the automatically-controlled station, and the other three following the trend either manually, as observed on a totalizing meter, or under load dispatcher's orders. If these latter three, or at least the one or two of them making the largest load variations, could make their change in load before the full-load change of the automatic station has been completed, the burden on the automatic station would be very sharply reduced.

The experience in Chicago with two stations operating simultaneously (figure 5) indicates that the burden on either one is less than half what it would be if only one were on automatic control. This indication has proved so definite that steps are now being taken to extend the automatic control to practically all the major generating stations. The so-called base-load stations during the minimum hours become the variable-load stations on the system, and at these hours take over the automatic regulation.

Relation of Controllers to Governors

The function of the auxiliary speed device or frequency controller, as it is commonly called, does not supersede that of the speed governor. The speed governor must continue to maintain instantaneous frequency, but in maintaining this frequency it distributes the load in a manner that is often not desired. The controller, on the other hand, is relatively slow in its action, but it does give droop correction, which the governor cannot do, and it can easily be made to properly allocate the load in any proportions desired. The importance of the governor seems to vary inversely with the size of the electrical system.

Figure 6 shows the frequency variation in a large system while it was part of a much larger interconnection and also while it was being operated isolated. Certainly it is apparent that the smaller systems, especially if supplying variable loads, must have the turbines equipped with the best governors available. In the large interconnections, on the other hand, there is an enormous inertia effect available, which holds the system speed within a very narrow band. This has led to the belief in some quarters that the governors should not be too sensitive and may even have a small dead band.

The load-control problem is generally rather easily handled in a small isolated system. The large interconnection-load control is much more difficult. Although the instantaneous frequency varies but little from minute to minute, it does drift over the longer period of hours or more, over a much wider band than is found in the small systems. This is a load-control problem, which must be handled by the controllers or by supplementary manual action.

The manufacturers have proposed that governors be built with a sensitivity of 0.04 per cent and a per cent regulation up to two per cent. These are undoubtedly desirable on the smaller systems, but on the large interconnections governors with a sensitivity of 0.08 per cent and from four per cent to six per cent regulation would be satisfactory. Where flat tie-line regulation is used, the action of too responsive governors is contrary to the action called for by the controllers. With the tie-line bias principle, however, more responsive governor action could easily be accommodated by increasing the amount of bias setting. The problem of modernizing enough governors in a large interconnection, where they may run up to 1,000 in number, so that a few will not be carrying a large portion of the regulation, is very difficult, and also the benefits to be derived from such a program are probably quite limited.

Conclusions

1. A centrally located frequency control with automatic tie-line controllers maintaining the proper loads locally, has proved to be a practical method of holding steady the frequency in large interconnections, regardless of size or numbers of interconnections.

2. The tie-line biased-by-frequency principle relieves the regulating burden on both the frequency control and the tie-line regulation stations.

3. Several of the variable-load stations in any group should be sharing the automatic regulation.

4. Adequate governors are necessary, but it appears that the sensitivity and per cent regulation of these governors may vary inversely with the size of the systems and the nature of the load.

Modern Relaying for A-C Secondary Network Systems

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Synopsis: This paper outlines the application of a new three-phase, single-element induction cylinder network master relay which uses line-to-line connected potential coils. Previous network master relays were three-phase, three-element and employed line-to-neutral connected potential coils.

The new relay with line-to-line connected potential coils produces far greater tripping torque during unbalanced primary feeder faults than the older relays with line-to-neutral connected potential coils. Examples are given to show the advantage of the new relay.

Modern relays have materially improved tripping characteristics which extend the range of highly leading and lagging currents over which the relays will operate selectively at normal balanced three-phase voltages.

The mechanical improvements of the network relays are discussed.

Introduction

DURING the past decade there have been many improvements in relays for a-c secondary network systems. There have been no basic changes in the functions performed by these relays. However, the introduction of a new single-element, three-phase induction cylinder relay with line-to-line connected potential coils and improved electrical and mechanical features, represents a basic change in the design and performance of these relays. The major improvements have been made in tripping performance and mechanical construction.

In the conventional *a-c secondary network system*,[1] figure 1, a secondary grid is fed by a number of network transformers which are supplied from a substation through two or more high-voltage feeders. The function of the network protector, located on the secondary of each transformer, is to disconnect automatically all transformers, on a faulty feeder, from the secondary grid. Hence, the grid will remain energized and continue to supply all loads from the healthy primary feeders. After the faulty feeder has been restored to normal and re-energized, it is the second function of the network protector to automatically reconnect the transformers on that feeder to the secondary grid.

The tripping of the network protectors is performed by a three-phase power directional relay, commonly called the "master relay," and the reclosing is performed by the same three-phase relay in conjunction with a single-phase "phasing relay."

Secondary network systems are now being more generally applied to areas which are relatively *lightly loaded*.[1] Installations in these areas are characterized by wide spacing of transformers, and relatively high secondary grid impedance, and consequently *lower fault voltages and currents* during primary feeder faults than are generally encountered in heavy-density systems which are more closely coupled. Hence, it is more difficult for the master relay to operate to trip the network protector during primary feeder faults in light-density than in heavy-density secondary network systems.

New Single-Element Master Relay

The new single-element three-phase master relay, figure 2 (right) overcomes this difficulty first because on three-phase primary feeder faults it produces more torque in proportion to the weight of the moving element than does any other master relay. Hence, there is a greater margin between the total torque and the friction torque which increases the useful torque available for operating the relay.

Further improvement is obtained by using *line-to-line (L-L) instead of line-to-neutral (L-N) potential coil connections.* This parallels transmission line relay practice where most directional relays use *L-L* connected potential coils. A

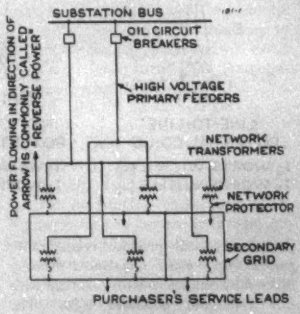

Figure 1. Schematic diagram of a-c secondary network system

Figure 2. Three types of three-phase network master relays

Left—Three-element induction disk relay

Center—Three-element induction cylinder relay

Right—Single-element induction cylinder relay

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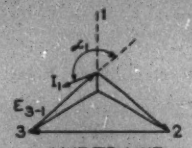
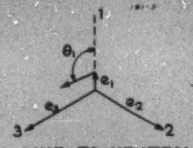
1. For all numbered references, see list at end of paper.



LINE-TO-LINE POTENTIAL COILS

I_1 WORKS WITH E_{3-1}



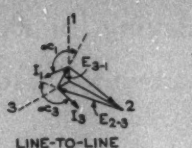
LINE-TO-NEUTRAL POTENTIAL COILS

I_1 WORKS WITH e_1

Figure 3 (left). Vector diagram of line-to-ground primary feeder fault

Figure 4 (right). Vector diagram of double line-to-ground primary feeder fault

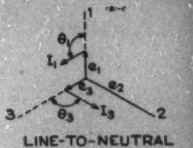
Both wye-connected high-voltage windings in network transformer



LINE-TO-LINE POTENTIAL COILS

I_1 WORKS WITH E_{3-1}

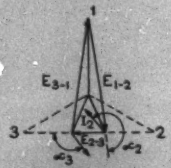
I_3 WORKS WITH E_{2-3}



LINE-TO-NEUTRAL POTENTIAL COILS

I_1 WORKS WITH e_1

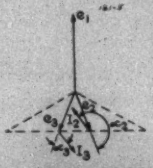
I_3 WORKS WITH e_3



LINE-TO-LINE POTENTIAL COILS

I_3 WORKS WITH E_{2-3}

I_2 WORKS WITH E_{1-2}



LINE-TO-NEUTRAL POTENTIAL COILS

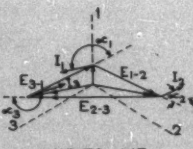
I_2 WORKS WITH e_2

I_3 WORKS WITH e_3

Figures 5 and 6. Vector diagrams of line-to-line primary feeder faults

(Left). Wye-connected high-voltage winding in network transformer

(Right). Delta-connected high-voltage winding in network transformer

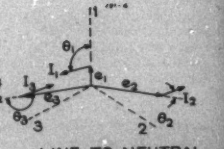


LINE-TO-LINE POTENTIAL COILS

I_1 WORKS WITH E_{3-1}

I_2 WORKS WITH E_{1-2}

I_3 WORKS WITH E_{2-3}



LINE-TO-NEUTRAL POTENTIAL COILS

I_1 WORKS WITH e_1

I_2 WORKS WITH e_2

I_3 WORKS WITH e_3

given relay will produce considerably *greater torque under unbalanced primary feeder fault* conditions with *L-L* than with *L-N* connected potential coils. The torque produced during three-phase primary feeder faults or under balanced three-phase conditions is the same for a given relay whether *L-L* or *L-N* potential coil connections are used.

The greater ratio of torque to weight of moving element makes the single-element relay attractive for use in heavy-density secondary network systems as well as in light-density secondary network systems. The *L-L* potential coil connections are advantageous for master relays used in heavy-density networks because there is always some reduction in voltage when unbalanced primary feeder faults occur. Therefore, the new single-element master relay, although originally developed for light-density network systems, is now applied to heavy-duty network protectors for heavy-density networks. The following discussion applies to network systems in general.

Relay Performance During Unbalanced Primary Feeder Faults

The advantage of the three-phase single-element relay with *L-L* connected potential coils can be readily seen by referring to figure 3 and table I. In table I comparisons are made at three different voltages. Figure 3 is a vector diagram of the voltages existing at the relay for *a line-to-ground primary feeder fault on a wye-connected transformer*. There is fault current I_1 in only one phase of the system, and hence only one phase of the master relay. With the older relays, with *L-N* connected potential coils, this current I_1 reacts with line-to-neutral voltage e_1 which is very small and the power factor is very low. With the new three-phase single-element relay with *L-L* connected potential coils, the torque is considerably greater because the same fault current I_1 reacts with line-to-line voltage E_{3-1} which is far greater in proportion to normal than e_1. Furthermore, the fault current is closer to the maximum torque position of the *L-L* relay, which further increases its torque.

Other possible unbalanced primary feeder faults are: (1) double line-to-ground, and (2) line-to-line faults. The actual torques for two similar relays with *L-N* and *L-L* connected potential coils are compared in table II.

The vector diagrams in figures 4, 5, and 6 show pictorially the relation between the fault voltages and currents in the two relays employing *L-L* or *L-N* potential connections.

The increased torque of the new relay during unbalanced primary feeder faults provides more positive operation and also increases the speed of operation of the relays, table III.

Hence, it permits more latitude in selection of network-protector fuses without the probability of a fuse blowing on unbalanced primary feeder faults before the master relay trips the network protector.

The greater torque of this relay has proved particularly advantageous where higher reverse power settings are required to prevent "pumping" of the network protector during normal operation. These higher settings may actually prevent a relay with *L-N* potential coils from tripping during certain unbalanced primary feeder faults. The greater torque produced by the single-element relay with *L-L* connected potential coils permits greater reverse power settings without the relay failing to trip on unbalanced primary feeder faults.[3]

Singe-Phase Switching of Primary Feeders

In some installations light-density networks are fed from overhead 4-kv wye-connected primary feeders with *single-phase switching* at the source or single-phase fuses between the source and the network transformers. A single phase-to-ground primary feeder fault may open only the faulty phase at the substation or at the fuse. Then there is reverse power on one phase being fed from the secondary grid through the transformer. This produces a tripping torque on one phase of the master relay. The other two phases may be supplying load to the network grid and this would produce a non-tripping torque in the other two phases of the master relay. If the relay is to trip the protector the torque produced by the fault current and voltage in one phase must overcome the torque produced

Table I. Comparison of Relays for Line-to-Ground Fault, Figure 3

Fault Current (I_f)* (Per Cent)	Potential Coil Voltage Which Operates With (I_f)*	Angle Between Fault Current and Maximum Torque Angle of Relay (Degrees)	Per Cent of Normal Torque** L-L Relay	Per Cent of Normal Torque** L-N Relay	Ratio of Relay Torque L-L to L-N
200	10% e_1	75	1.7		15.30
200	58% E_{2-1}	47	26		
500	25% e_1	75	11		6.1
500	71% E_{2-1}	55	67		
1,400	70% e_1	75	81		1.70
1,400	85% E_{2-1}	51	139		

*Fault current and potential coil voltage are in per cent of rated current and voltage of associated network transformer.

**Normal torque is the torque produced by the relay with all three phases energized with rated voltage and rated current at the angle of maximum torque.

Table II. Comparison of Master Relays for Various Types of Unbalanced Primary Feeder Faults, Figures 4, 5, and 6

Basis: Fault Voltage Equals 25 Per Cent of Normal. Power Factor of Fault Current 75 Degrees Lagging

Type of Fault	Transformer Primary Connection	Per Cent of Normal Torque L-L Relay	Per Cent of Normal Torque L-N Relay	Ratio of L-L to L-N Relay Torques
Double line-to-ground	Wye	$15.1\frac{I^*}{I_n}$	$4.2\frac{I}{I_n}$	3.6
Line-to-line	Wye	$24.8\frac{I}{I_n}$	$3.7\frac{I}{I_n}$	6.7
Line-to-line	Delta	$21.4\frac{I}{I_n}$	$3.2\frac{I}{I_n}$	6.7

*$\frac{I}{I_n}$ = Ratio fault current to rated current of network relay.

by the load current in the other two phases. The increased tripping torque of the single-element relay with *L-L* potential coil connections will be beneficial in these cases. Single-phase switching on primary feeders to secondary networks *is to be avoided wherever possible.*

Relay Connection

The basic differences in *L-L* and *L-N* potential coil connections are shown in figure 7. In this figure the *L-L* connections are shown to involve three potentials for the sake of simplicity. The actual connections of the new three-phase single-element master relay[4] are shown in figure 8. This relay uses two sets of potential coils in open delta.

Improved Tripping Characteristics

In addition to tripping on primary feeder faults as outlined above, network master relays must trip on very low values of reverse power flow (i.e., power flow from the grid to the network) such as transformer-core loss and cable-charging current, to enable clearing a primary feeder by merely opening the station breaker.

Since the relay must function on *very small power reversals* involving very highly leading cable charging current I_c and lagging transformer exciting current I_m, the ideal tripping characteristic would be that of a true wattmeter or curve *a-a'*, figure 9.

Practically, it is not possible to build a relay which has a truly wattmeteric characteristic because of the saturation of the iron used in the magnetic structures of the relay and the current transformers. The effect of saturation is to produce a characteristic like that of *c-c'*, figure 9. Currents through the protector represented by vectors terminating to the left of the characteristic will cause the master relay to trip the protector. Current vectors terminating to the right will not cause the master relay to trip the protector.

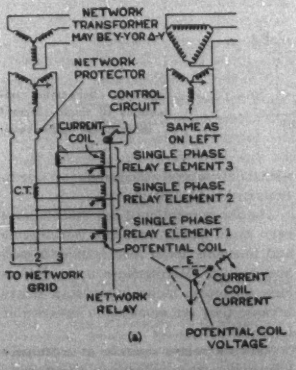
Improvements in the *quality of iron* available and refinements of the design of the *magnetic structures* of the relay have resulted in tripping characteristic *b-b'* (figure 9) for the modern induction cylinder single-element and three-element, three-phase master relays as compared with characteristic *c-c'* for early types of induction disk master relays.

The newer induction cylinder master relays with straighter characteristics enable more universal application as they permit selective operation with larger highly leading and lagging currents. The characteristics of earlier induction disk master relays were so bent that it would

Table III. Comparative Operating Times of Similar Relays on Single Phase-to-Ground Primary Feeder Faults, Figure 3, With L-L and L-N Connected Potential Coils

Fault Voltage 25 Per Cent Normal and Power Factor of Fault Current 75 Degrees

Fault Current In Per Cent of Normal	Operating Time in Seconds L-L Relay	Operating Time in Seconds L-N Relay
500	0.16	0.9



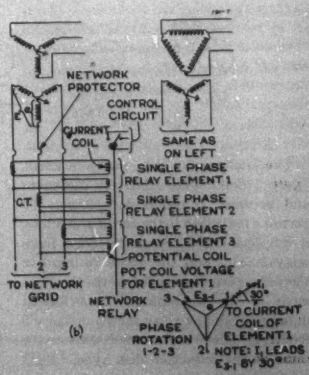


Figure 7. Schematic diagram of network master relay connections

(*a*)—Line-to-neutral connected potential coils

(*b*)—Line-to-line connected potential coils

Table IV. Comparison of Mechanical and Electrical Characteristics of Two Types of Older Three-Phase, Three-Element Master Relays and the New Single-Element, Three-Phase Master Relay

Type of Relay	Watts Input (Per Cent)	Torque Per Watt (Per Cent)	Ratio Torque to Weight of Moving Element (Per Cent)	Volume (Per Cent)
Three-phase, three-element induction disk relay (old)	100	100	100	100
Three-phase, three-element induction cylinder relay (old)	45	320	209	42
Three-phase single-element induction cylinder relay (new)	26	465	231	33

not be to the right of both I_c and I_m. Hence, it was necessary to adjust the characteristics of many of these relays to meet varying conditions and to restrict their application to locations where cable-charging currents were negligible.

Mechanical Improvements

The mechanical improvements of network relays can be seen in figure 2 and table IV where the principal characteristics were given.

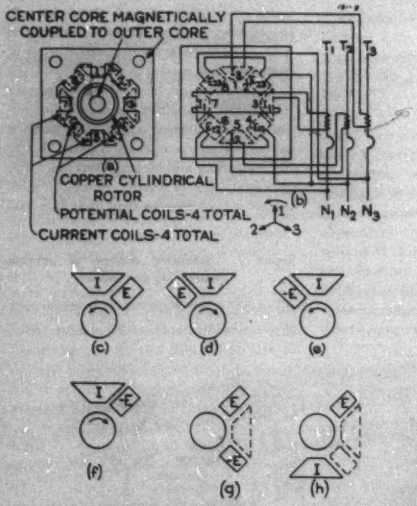


Figure 8. Schematic connections of single-element three-phase master relay

The induction disk master relays, figure 2 (left), were relatively inefficient and occupied considerable volume. To permit a reduction in the size of protectors, it was desirable to reduce the size of these relays. This and the desire to improve the relay performance led to the development of the three-phase three-element induction cylinder relay shown in figure 2 (center). Electrically, this relay was the same as the induction disk type, i.e., it had three independent single-phase elements all on a common shaft and had *L-N* connected potential coils. The new single-element relay is a further improvement of the induction cylinder design in that all three phases are combined in one element with only one rotor.

Network relay adjustments have been simplified in that individual phase adjustments are not required. *Drag magnets* which were a source of maintenance on the older relays have been eliminated. Contacts have been developed that will withstand several thousands of operations without maintenance.

The above-mentioned refinements have been made mainly to *reduce maintenance* and to enable *longer time between inspection periods*. Maintenance is a particularly important factor in network relays because they are mounted in inaccessible locations.

Network relays operate at extremely low torques when tripping on transformer exciting current. Hence, friction plays an important part in the performance of these relays. The single-element master relay has a much lighter moving element; hence, the *friction force is lower*, and consequently operation is more positive. Induction cylinder relays have balanced magnetic circuits and are inherently free from vertical vibration. Hence the major source of bearing wear has been eliminated.

Modern network relays operate at a *lower temperature rise*, i.e., about 40 degrees centigrade rise over ambient around relay, to allow for higher ambients encountered inside higher capacity submersible network protectors now being built, without unduly shortening the life of the relay coils.

Summary

A new three-phase, single-element induction cylinder relay has been introduced which, although functionally the same as previous relays in so far as network-protector control is concerned, has:

1. Line-to-line connected potential coils instead of line-to-neutral connected potential coils which provides a far greater tripping torque during unbalanced primary feeder faults.

2. This is particularly advantageous in light-density network systems where fault currents and voltages are lower than in heavy-density systems which are more closely coupled. The line-to-line connected potential coils offer advantages in heavy-density systems too.

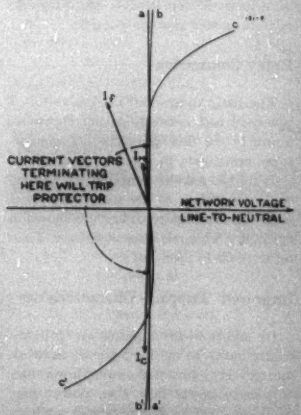


Figure 9. Network master relay tripping characteristics

I_c—Cable charging current
I_f—Short-circuit current
I_M—Transformer exciting current

Five Years' Experience With Ultrahigh-Speed Reclosing of High-Voltage Transmission Lines

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Synopsis: The data covering five years' operating experience with 33 ultrahigh-speed reclosing breaker installations mainly on a large interconnected and integrated high-tension system are presented and analyzed, and conclusions based on this experience are drawn. Out of 71 cases of flashover cited, 65 reclosures were successful and 6 cases of reclosure resulted in restrikes, a record of 91.5 per cent successful reclosures. The conclusions drawn are that not only is actual performance better than appeared possible when the development was first made but that further improvements are possible by further reducing breaker time.

I. Introduction

THE basic principles of ultrahigh-speed reclosing of high-voltage transmission lines have been previously presented[1] in a paper before the Institute. Likewise, operating experience with the original high-speed reclosing equipment first developed and with a modification of that equipment were presented[2] two years ago. However, the data available at that time covered only three sections (six terminals) of high-voltage transmission lines and a period of only three years, in one section of which the equipment was in service for only one year and another the equipment was in service for only a portion of one year, so that operating experience with only 15 cases of reclosure could be cited and discussed. Since then, however, the application of ultrarapid reclosure has not only been widely extended but a great many more operations have been experienced. These now constitute a set of data that is extensive enough to be able to furnish a basis for some well-founded conclusions. It is the purpose of this paper to present and analyze these data and draw such conclusions therefrom as are warranted and pertinent.

II. System on Which Installed

The system on which all terminal equipments with the exception of four (representing two line sections) have been installed is the central system of the American Gas and Electric Company. This is shown diagrammatically in figure 2. This system is an integrated system operating in seven states and comprising altogether 1,455 miles of 132-kv transmission, substantially all of which is of double-circuit steel-tower construction with a total, as of the date of writing, of 2,483 miles of circuit. It serves a load whose last-recorded maximum one-hour integrated peak was 997,000 kw. On this system the power supply, that is, power generation and power transmission to load centers, is integrated and co-ordinated to the highest degree. The system, which is a predominantly steam-electric system, nevertheless has a substantial portion of hydro capacity. Besides this, extensive and important foreign interconnections exist on several portions of the system through which diversity and other exchanges are carried out with adjacent systems. This, coupled with the diversities in load and, to some extent, of time over the system, makes imperative frequent and in many cases sudden changes in power flow over many of the important transmission lines on the system. Besides that, the availability of economical supplies of hydro in portions of the system and the concentration of generation by steam-electric stations at the points where combined optimum fuel and water conditions prevail, make economically desirable and necessary the transfer of heavy flows of power, at one time or another, over most of the transmission lines on the system. Under these conditions, the importance of continuity of supply, if the entire system is to operate in accordance with predetermined principles of economy, is apparent. Hence, the first and so far the widest application for ultrahigh-speed reclosing has been found on that system.

The four remaining terminals not installed on the central system are on the double-circuit Deepwater-Atlantic City lines of the South Jersey system. These two circuits are installed on 132,000-volt towers and insulated for that voltage but are operating at present at a voltage of 66 kv.

The first installation using the experimental equipment was on the Fort Wayne-Deer Creek circuit in Indiana. As will be noted from the diagram, since then 27 additional terminals (13 line sections) on the system have been installed covering a total circuit mileage of 655 miles. These have been extended progressively as the need for them arose and as the operating advantages or necessities were indicated.

III. Operating Experience

A summary of the total operating experience since the first installation is given in table I. Referring to that table it will be seen that taking the two systems which the record covers, a total of 33 terminals involving 16 line sections have been covered, and that these 16 line sections cover approximately 840 circuit miles of line, all but 126 of which operate at 132,000 volts. In the period May 1936 to November 1940, covering substantially five lightning years, 72 cases

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1. For all numbered references, see list at end of paper.

3. The tripping characteristics have been improved to permit operation at normal voltage over a wider range of highly lagging and highly leading currents.

4. There have been many mechanical improvements in network relays which have improved their performance and reduced maintenance.

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WHEN TO START A NETWORK, D. K. Blake. *Electrical World*, volume 95, February 15, 1930, page 347.

HOW TO START A NETWORK, D. K. Blake. *Electrical World*, volume 96, July 19, 1930, page 115.

2. WHERE TO USE LIGHT-DENSITY NETWORKS. D. L. Beeman. *Distribution*, July 1939, pages 10-11.

3. LIMITATIONS ON SETTINGS OF NETWORK RELAYS, D. L. Beeman. *Distribution*, January 1940, page 13.

4. A SINGLE-ELEMENT POLYPHASE DIRECTIONAL RELAY, A. J. McConnell. AIEE TRANSACTIONS, volume 56, 1937 (January section), pages 77-80 and 113.

of flashover resulting in line opening occurred. Of these, 63 cases were single-line trouble and 9 cases were two-line trouble. Out of the same number of 72 cases of flashover, 65 reclosures were successful and 7 cases of reclosure resulted in restrikes. This is a record of 9.7 per cent unsuccessful reclosures; but in this connection it needs to be pointed out that in one of these cases permanent physical damage had previously resulted to a tower and that under such conditions obviously successful reclosure was a physical impossibility since nothing but a permanent outage could clear the trouble. Disregarding, therefore, this one case, the total unsuccessful reclosures were six, representing a percentage slightly over eight per cent. An interesting thing in this connection, too, is that in not a single case did the equipment fail mechanically, that is, the mechanical performance was in every case perfect and reclosure was carried through and was successful in every case where the circuit condition permitted re-energization of the line. Table I shows clearly, too, the rapid accumulation of experience with the year 1940. It will be noted that the percentage of restrikes or unsuccessful reclosures for 1940 was again slightly over eight per cent, the same figure as for the total five-year period.

The table further shows the distribution of faults between phase to ground, phase to phase and ground, and three phase. Of the 71 cases of flashover, 55 cases were phase-to-ground faults on one line with 53 successful reclosures and only two restrikes which were probably due to multiple lightning stroke as explained in previous paper.[2] Three cases of phase-to-phase and ground faults on one line occurred, all of which reclosed successfully. Five cases of three-phase faults on one line occurred with three successful reclosures and two restrikes. Three cases of phase-to-ground faults on two lines occurred, all of which reclosed successfully. Four cases of phase-to-phase and ground faults on two lines occurred with three successful reclosures and one restrike. One case of three-phase fault on two lines occurred which restruck.

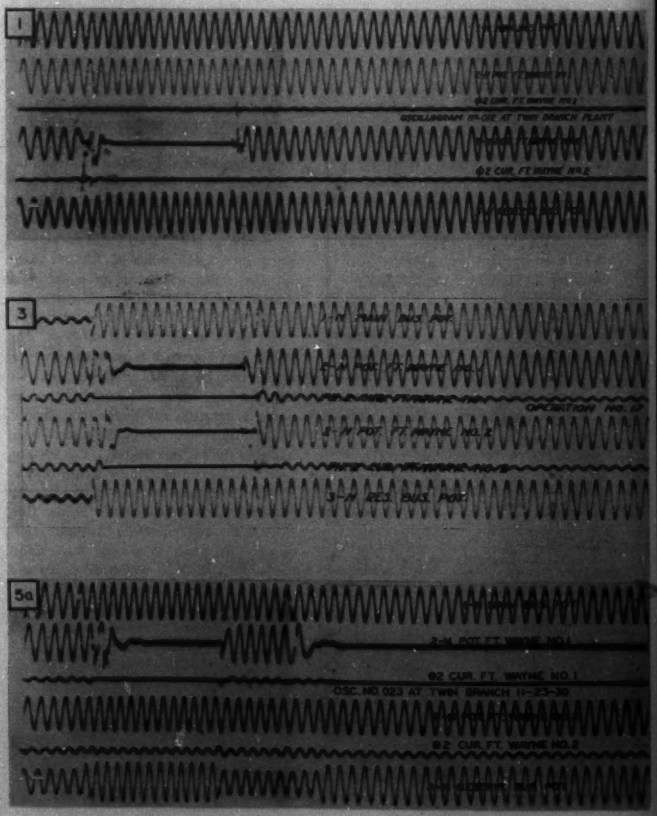
IV. Some Typical Oscillograms and Their Significance

In figure 1 are shown five sets of oscillographic records taken at Twin Branch station showing system performance for five typical cases of trouble on the system. The top and bottom traces on all oscillograms represent phase 1-to-neutral and phase 3-to-neutral voltages respectively on 132-kv bus at Twin Branch station. The second and fourth traces from the top indicate phase 2-to-neutral voltages of number 1 and number 2 Twin Branch-Fort Wayne lines respectively taken on the line side of the breakers at Twin Branch station. The third and fifth traces from the top represent phase 2 line currents on number 1 and number 2 Twin Branch-Fort Wayne lines respectively.

Oscillogram number 1 is a record of a lightning flashover on number 2 Twin Branch-Fort Wayne line involving phase 3 to ground that occurred at 9:34 p.m. on July 22, 1939. The fault was cleared in approximately $6^1/_2$ cycles and after a line de-energization of 12 cycles, reclosure was entirely successful.

Oscillogram number 2 is a record of a lightning flashover on number 1 Twin Branch-Fort Wayne line involving phase 1 to ground that occurred at 2:21 p.m. on June 18, 1940. The fault was cleared in approximately eight cycles and after a line de-energization of seven cycles, the line was re-energized from one end and three cycles later the breaker at the other end reclosed. The difference in reclosing times of the two breakers was due to the experimental adjustment of breaker-contact operating speed which existed at this time. With this adjustment the breaker contacts reached a point five-eighths inch from contact "make" position after 15 cycles and hesitated at this point, completing the stroke at 18 cycles. It is believed that when the five-eighths inch point was reached, the breaker at one end of the line arced across its contacts, thus energizing the line. As soon as the line was energized, most of the potential

Figure 1. Oscillograms of actual operation on the 132-kv transmission system of the central system

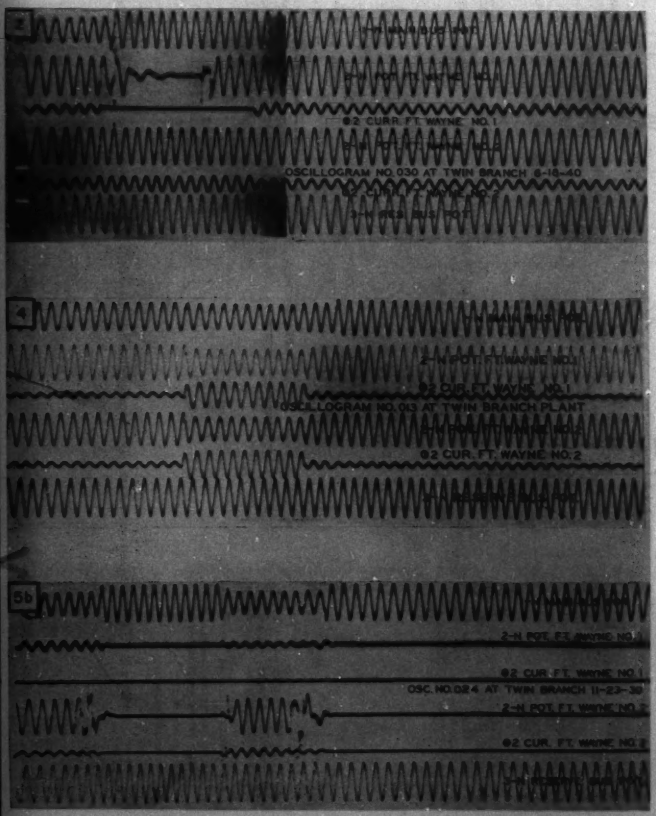


across the contacts of the breaker at the other end disappeared and the circuit was therefore not closed until electrical contact was finally made by the second breaker at 18 cycles.

Oscillogram number 3 is a record of lightning flashover occurring simultaneously on number 1 and number 2 Twin Branch-Fort Wayne lines involving phases 1 and 3 to ground that occurred at 12:50 a.m. on July 8, 1939. Both lines were opened at both ends in approximately $6\frac{1}{2}$ cycles after the inception of the fault and after both lines had been de-energized for $11\frac{1}{2}$ cycles, reclosure of all four breakers on both lines was entirely successful.

Oscillogram number 4 is a record of lightning flashover occurring simultaneously on Fort Wayne-Deer Creek and Fort Wayne-Delaware lines involving phases 1 and 2 to ground that occurred at 12:13 a.m. on July 23, 1939. At this time the Fort Wayne-Deer Creek line only was equipped with ultrahigh-speed reclosing equipment, which line reclosed successfully. The Fort Wayne-Delaware line was only protected with instantaneous overcurrent relays in conjunction with time-delay overcurrent relays. Under these conditions, it is to be noted that both lines opened up at both ends $10\frac{1}{2}$ cycles after the inception of the fault.

Oscillogram number 5 is a record taken when mechanical damage occurred to a steel tower on number 1 and number 2 Twin Branch-Fort Wayne lines at 9:54 p.m. on November 23, 1939. From the oscillogram it will be noted that a fault involving phase 3 to ground occurred first on number 1 line, which opened at both ends $7\frac{1}{2}$ cycles after the inception of the fault and reclosed after de-energization of the line for ten cycles and reopened due to permanent trouble on the line section. Approximately 30 cycles later number 2 line became involved in the trouble with phase 1 going to ground, opening both ends after $6\frac{1}{2}$ cycles and reclosing after line had been de-energized 12 cycles when it retripped on account of permanent trouble on the line section.


3
#2 CURR. FT. WAYNE NO. 1
OSCILLOGRAM NO. 030 AT TWIN BRANCH 6-18-40
4
2-H POT. FT. WAYNE NO. 1
#2 CUR. FT. WAYNE NO. 1
OSCILLOGRAM NO. 063 AT TWIN BRANCH PLANT
#2 CUR. FT. WAYNE NO. 2
5b
2-H POT. FT. WAYNE NO. 1
#2 CUR. FT. WAYNE NO. 1
OSC. NO. 024 AT TWIN BRANCH 11-23-39
2-H POT. FT. WAYNE NO. 3
#2 CUR. FT. WAYNE NO. 3

V. Additional Installations

The accumulated operating experience has been so beneficial and the results obtained so much greater than even the authors originally anticipated that as the continuity problem and the problem of reliability of supply had to be met on other sections of the system, ultrarapid reclosure was extended and is still being extended today. Thus at the present time there are 12 additional terminals in process of installation covering additional 6 line sections with a total 224.2 miles of 132-kv circuit. These are clearly indicated in the diagram figure 2. Other points on the central system, and on the other two systems of the American Gas and Electric Company where the same general problem is being studied, are being seriously considered for equipment with ultrarapid reclosure on the terminal breakers and there is no doubt in the authors' minds that such additional applications will be found desirable and/or necessary. Particularly is attention being given to medium-voltage lines in the subtransmission or distribution class such as those of 23,000-volt and 33,000-volt rating. Here, however, the problem that still has to be solved is the one of providing an economical reclosing mechanism and a relay arrangement that will combine the basic elements of one cycle differential operation without the expense involved in the present system. While neither of these two problems has been entirely worked out the present indications are that both can and will be.

VI. Conclusions

Based upon the five years' experience studied and discussed here the authors believe that the following conclusions are clearly indicated:

1. In general on a high-voltage system properly insulated and provided with ground-wire protection at least 90 per cent successful reclosure can be expected by the use of ultrarapid reclosing. In the case of the two systems cited and discussed, out of 72 operations 71 were apparently due to lightning and of these 65 reclosures were successful. This is a record of better than 91 per cent successful operation and compares with the previously indicated figure of not less than 75 per cent successful operation.

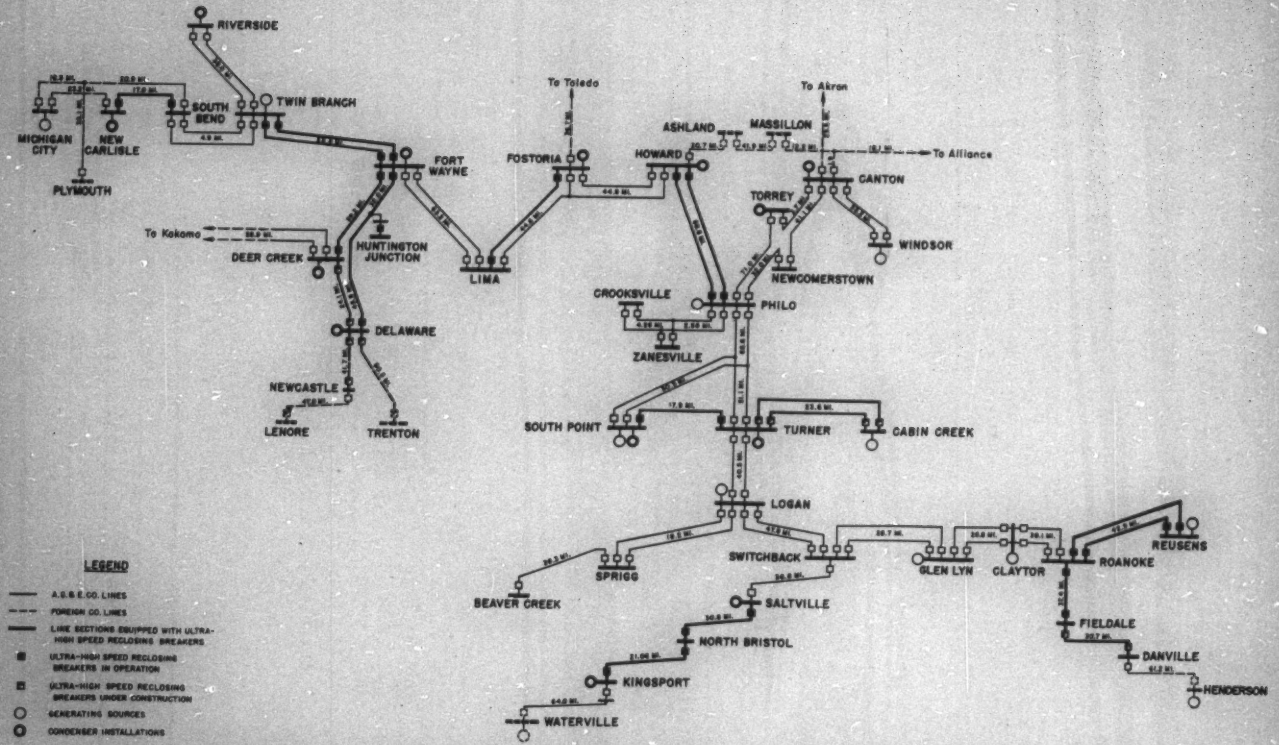


Figure 2. Ultrahigh-speed reclosing oil circuit breaker installations on the 132-kv transmission system of the central system of the American Gas and Electric Company

Table I. Summary of Actual Operations of 132-Kv Ultrahigh-Speed Reclosing Oil Circuit Breakers, May 1936 to November 1940

Line	Line Voltage (Kv)	Length of Line (Circuit Miles)	Number of Terminals Involved	Date of Installation	Ultrahigh-Speed Oil Circuit Breaker Operations: Number of Operations 1936	1937	1938	1939	1940	Total	Number of Successful Reclosures 1936	1937	1938	1939	1940	Total	Number of Restrikes 1936	1937	1938	1939	1940	Total	Types of Faults: Phase to Ground 1936	1937	1938	1939	1940	Total	Phase to Phase to Ground 1936	1937	1938	1939	1940	Total	Three Phase 1936	1937	1938	1939	1940	Total
Fort Wayne-Deer Creek	132	59.2	2	5/17/36	4	5	3	1	3	16	3	4	3	1	3	14	1	1				2	4	5	3	1	3	16												
South Bend-New Carlisle	132	17.0	2	1/29/38			1	1		2			1	1		2									1	1		2											
No. 1 Twin Branch-Fort Wayne	132	65.4	2	8/31/38				1	2	3				1	2	3										1	2	3										
No. 2 Twin Branch-Fort Wayne	132	65.4	2	7/25/38			2	3	1	6			2	3	1	6									2	3	1	6										
Nos. 1 and 2 Twin Branch-Fort Wayne	132		4	8/31/38				2		2				1		1				1		1										1		1				1	1
Fort Wayne-Delaware	132	77.9	3	5/26/40					1	1					1	1											1	1										
Saltville-North Bristol	132	30.8	2	3/22/40					6	6					6	6											3	3					1	1				2	2
North Bristol-Kingsport	132	21.1	2	3/20/40					6	6					4	4				2		2					3	3										3	3
Roanoke-Fieldale	132	37.35	2	4/28/40					12	12					12	12											10	10					2	2					
No. 1 Roanoke-Reusens	132	42.89	2	5/ 1/40																																			
No. 2 Roanoke-Reusens	132	42.89	2	5/ 1/40					3	3					3	3											3	3											
Nos. 1 and 2 Roanoke-Reusens	132		4	5/ 1/40					6	6					4	4				2		2					3	3					3	3					
No. 1 Philo-Howard	132	80.6	2	5/ 2/40					3	3					3	3											3	3											
No. 2 Philo-Howard	132	80.6	2	5/20/40					3	3					3	3											3	3											
No. 1 and No. 2 Philo-Howard	132		4	5/20/40																																			
Fostoria-Lima	132	44.6	2	10/3/40																																			
No. 1 Deepwater-Atlantic City	66	63.1	2	6/27/40																																			
No. 2 Deepwater-Atlantic City	66	63.1	2	6/27/40					2	2					2	2											2	2											
Nos. 1 and No. 2 Deepwater-Atlantic City	66		4	6/27/40					1	1					1	1																	1	1					
Turner-South Point	132	47.04	2	8/ 1/40																																			
Total		839.87	32		4	5	6	8	49	72	3	4	6	7	45	65	1	1		1	4	7	4	5	6	6	37	58					1	7	8				1	5	6

An Improved Polyphase Directional Relay

BERT V. HOARD
MEMBER AIEE

THE inductor-loop principle of operation has been employed successfully for many years in building single-phase directional relays of the high-speed type. This principle of operation has now been extended to obtain a high-speed polyphase directional relay of a radically different type of construction than has been employed heretofore, which has such features as simplicity, compactness, low burden, high sensitivity, and nonbounce contacts.

The trend toward high-speed operation for all types of protective-relay applications has developed a need for such a relay. This is particularly true in directional-comparison schemes of pilot relaying. Other applications include the use of a polyphase directional element with instantaneous overcurrent or impedance relays and for these applications high speed in the directional element is needed for proper co-ordination.

The principle of operation of the inductor-loop element is that of a conductor carrying current in a magnetic field. The inherent efficiency and simplicity of the magnetic circuit combined with low inertia of the inductor loop makes possible a directional-relay design having a high torque-to-weight ratio which is essential if sensitive, high-speed operation is to be obtained.

The arrangement of the components of

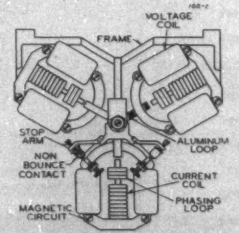


Figure 1. Diagram of electromagnets, loops, and contacts

such a relay element designed for three-phase operation is shown schematically in figure 1. It consists of three electromagnets and three loops around a vertical shaft. Each loop is mounted on the shaft with its outer side located in an air gap within the electromagnet. The voltage coils, one on each of the outer two legs of each electromagnet, have a voltage applied which induces a large current in the loop by transformer action. Current flowing through the current coil, which is located on the center leg of the electromagnet, produces an air-gap flux which interacts with the loop current in the outer side of the loop and causes rotation of the shaft in a direction corresponding to the flow of alternating current power. If the direction of current flow reverses, the torque and the direction of rotation of the shaft reverse. A photograph of the relay is shown in figure 2.

The phase-angle characteristic of the inductor-loop electromagnet is essentially that of a watt element, although maximum torque is obtained when the applied current is slightly lagging the voltage. In the voltage circuit the loop can be considered as the secondary load of a transformer which has a high resistance compared to its reactance, so that the loop current lags the primary voltage by an angle of about 15 degrees. In the current circuit the air-gap flux is in phase with the applied current. When loop-current and air-gap flux are in phase, maximum torque is obtained, hence this condition is fulfilled when the applied current lags the voltage by 15 degrees.

One loop and its associated electromagnet make up one phase of the three-phase relay, and a delta voltage and a star current are applied. For actual installations, the 90-degree connection is normally used for polyphase directional relays because during phase-to-phase faults more sensitive operation will be obtained, since the two elements carrying fault current have the two unfaulted

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2. The probability of restrike on double-circuit lines of the type existing on the central system in case of double-circuit flashovers is approximately four times as great as in the case of single-circuit flashovers. Thus, in the case of the two systems described, out of eight cases of two-line trouble (omitting the one due to permanent disability) two restrikes occurred or a restrike record of 25 per cent. On the balance of 63 cases of one-line flashover, four restrikes occurred or a restrike record of 6.5 per cent.

3. Ultrarapid reclosure has definitely established itself as an indispensable tool in high-tension integrated power systems. A definite start has been made in the direction of extending it to lower voltage lines. Further development here is needed and will depend upon the successful removal of the economic limitation to the extension of this application to such lower voltage and, therefore, lesser capacity lines.

4. There is reason to believe that the present 8.5 per cent unsuccessful operation can be reduced and particularly that the percentage of 25 per cent failure to reclose successfully on two-line faults can be reduced. The means for carrying this out so far indicated are as follows:

(a). Reducing the total percentage of two-line flashovers by further increasing the speed of clearing of the fault.

(b). Reducing the percentage of restrikes by speeding up the clearing time and thus permitting a corresponding increased waiting time before reclosure is attempted.

References

1. ULTRA-HIGH SPEED RECLOSING OF HIGH VOLTAGE TRANSMISSION LINES, Philip Sporn and D. C. Prince. AIEE TRANSACTIONS, volume 56, 1937, pages 81–90.

2. EXPERIENCE WITH ULTRA-HIGH SPEED RECLOSING OF HIGH VOLTAGE TRANSMISSION LINES, Philip Sporn and C. A. Muller. AIEE TRANSACTIONS, volume 58, 1939, pages 635–31.

Figure 2. Photograph of H-3 relay with glass cover removed

delta voltages applied to them, respectively. Using this connection, one of the electromagnets will have line current from phase *a* and the delta voltage opposite phase *a* applied. Thus, for unity power factor in the system, the current through the relay electromagnet is leading the applied voltage by 90 degrees, and for a fault which causes the system current to lag by 45 degrees the relay current leads the applied voltage by 45 degrees.

For the 90-degree connection the relay phase-angle characteristic should, therefore, be shifted so that maximum torque is obtained when the relay current leads the relay voltage by 45 degrees. A series resistance-phase shifter, similar to that commonly used in the induction-disk type relay cannot be used for the inductor-loop relay, because the latter has a voltage circuit which is mostly resistance. However, a series capacitor of the proper size will produce the 45-degree phase-angle characteristic as shown in the diagram of figure 3*a*.

A simpler phase shifter and one that is better from an operating and maintenance standpoint is the use of a phasing loop on the magnetic circuit in front of the current coil as shown in figure 1. The phasing loop consists of three heavy rectangular-shaped copper washers and causes the air-gap flux to lag behind the applied relay current, so that the current must be advanced in phase position to bring the loop-current and air-gap flux back in phase and obtain maximum torque. This type of phase shifter is used on the relay to obtain a 45-degree characteristic as shown in figure 3*b*. To obtain the same magnitude of air-gap flux and relay sensitivity, a larger number of turns are used on the current coil when phasing loops are used. Even with the increased number of turns required, the burden of the current circuit is very low as shown subsequently.

The instantaneous torque in any one electromagnet of the relay is produced by the instantaneous products of voltage (loop current) and current (air-gap flux) in the electromagnet, which is a double-frequency pulsating torque. Figures 4*a* and 4*b* show this torque respectively for phase angles when the average torque is a maximum and when it is zero. The torques in the other two electromagnets are also pulsating as shown, respectively, in figures 4*c* and 4*d*; however, they are displaced 120 degrees in time phase from each other and when all three instantaneous values are added up, the result is a uniform nonpulsating torque. Hence, under normal conditions with the three applied currents and voltage balanced there is no tendency for these torques to cause vibration. During unbalanced faults, in general, there will be a combination of a balanced torque and a pulsating torque on the moving element and the pulsating torque will tend to produce some vibration. However, this vibration has been minimized through proper moving element and contact design which keeps the contacts positively closed when the unbalanced torque is present.

The contact travel for any type of high-speed relay is necessarily small as one means of obtaining high speed. For this relay, due to its extremely high ratio of torque to inertia, the normal travel of 0.030 inch is greater than has been customarily used in the past for similar relays. Nonbounce contacts are used, which consist of a small enclosed cylinder partially filled with tungsten powder mounted on the end of a flexible spring. When the cylinder strikes the rigid stationary contacts, the particles of tungsten slide over each other and absorb the energy of impact. After the contact spring has been slightly deflected, the adjusting screw in the stop arm (figure 1) strikes the moving contact cylinder and then the full torque of the relay is transmitted to the moving and fixed contacts. Hence, the contacts act as the moving-element stop and full contact pressure is assured at all times. Connection is made to the moving contact by means of a very flexible copper-conducting strip.

Among the advantages obtained because of the loop type of construction is that large air gaps can be used between iron and loop which makes the element easy to inspect and eliminates the possibility of air-gap friction from foreign materials lodging in the gap. The efficiency of the design is such that very small burdens per phase are imposed. The voltage circuit requires 4.0 volt-amperes per phase at 115 volts and the cur-

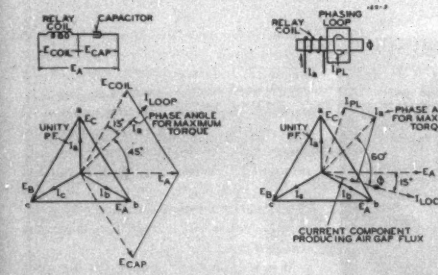
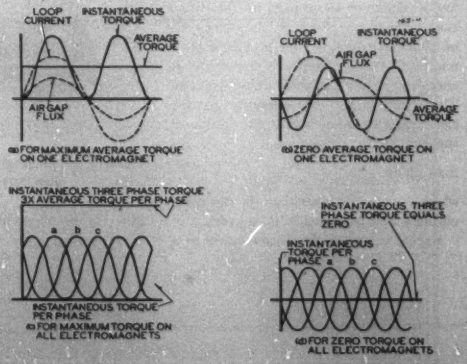


Figure 3. Vector diagram for phase (a) electromagnet using 90-degree connection

(*a*)—Using capacitor phase shifter in potential circuit to obtain maximum torque in relay when system-fault current lags by 45 degrees

(*b*)—Using phasing-loop phase shifter in current circuit, to obtain maximum torque in relay when fault current lags 45 degrees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AVERAGE TORQUE
AIR GAP FLUX
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(b) ZERO AVERAGE TORQUE ON ONE ELECTROMAGNET
INSTANTANEOUS THREE PHASE TORQUE 3X AVERAGE TORQUE PER PHASE
a b c
INSTANTANEOUS TORQUE PER PHASE
(c) FOR MAXIMUM TORQUE ON ALL ELECTROMAGNETS
INSTANTANEOUS THREE PHASE TORQUE EQUALS ZERO
INSTANTANEOUS TORQUE PER PHASE a b c
(d) FOR ZERO TORQUE ON ALL ELECTROMAGNETS

Figure 4. Torques produced in polyphase directional relay

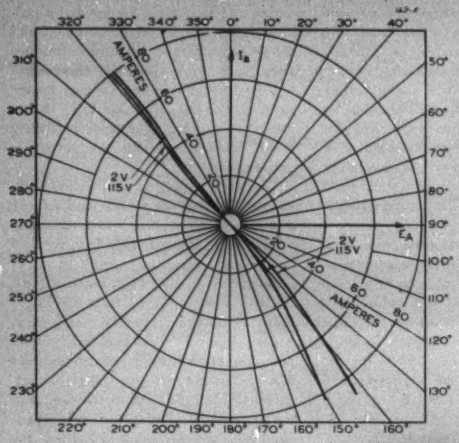


Figure 5. Phase-angle curves at 115 and 2 volts

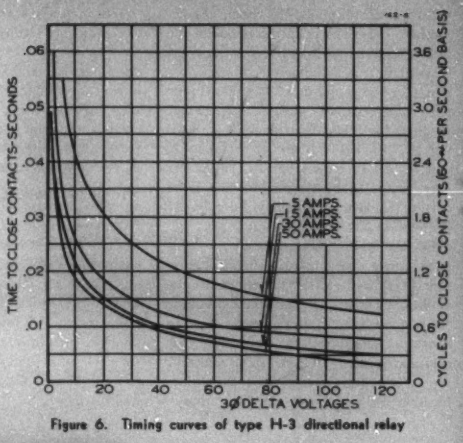


Figure 6. Timing curves of type H-3 directional relay

rent circuit, which also includes the phasing loops, requires 1.6 volt-amperes per phase at five amperes. The sensitivity of the relay is excellent, being less than one volt over a current range of 2.5 amperes to 100 amperes at the maximum torque phase angle. From the phase-angle curves shown in figure 5 it will be seen that the relay has adequate directional characteristics even at a very low voltage and high current.

Timing curves for the relay taken with a 0.030-inch contact gap are shown in figure 6. It will be seen that at 65 volts and above 15 amperes the timing is less than 0.6 cycle on a 60-cycle basis.

The directional relay is also made with a voltage-restraint element as shown in figure 7. The restraint element is mounted below the directional element and consists of three electromagnets and loops similar to those used on the directional element. However, the outer coils of each electromagnet are energized from one delta voltage, and the center coil is energized from another delta voltage. The phase-angle characteristic of the electromagnet is such that the torque of the element is proportional to:

$$E_1 E_2 \sin \theta$$

where θ is the angle between the two delta voltages and is normally 60 degrees.

Each electromagnet is connected to a different combination of delta voltages so that a uniform restraint torque and balanced burdens are obtained. During a three-phase fault the voltage-restraint torque is reduced in proportion to the square of the voltage, so that for low voltages it is negligible. During unbalanced faults when any one delta voltage becomes zero, the restraint is automatically removed, because one of the applied voltages becomes zero on two of the electromagnets, and on the third electromagnet the collapsed voltage has made the sine of θ zero.

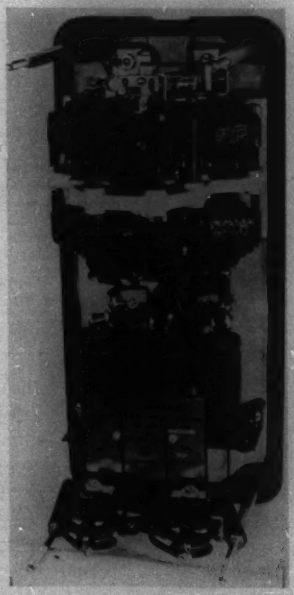
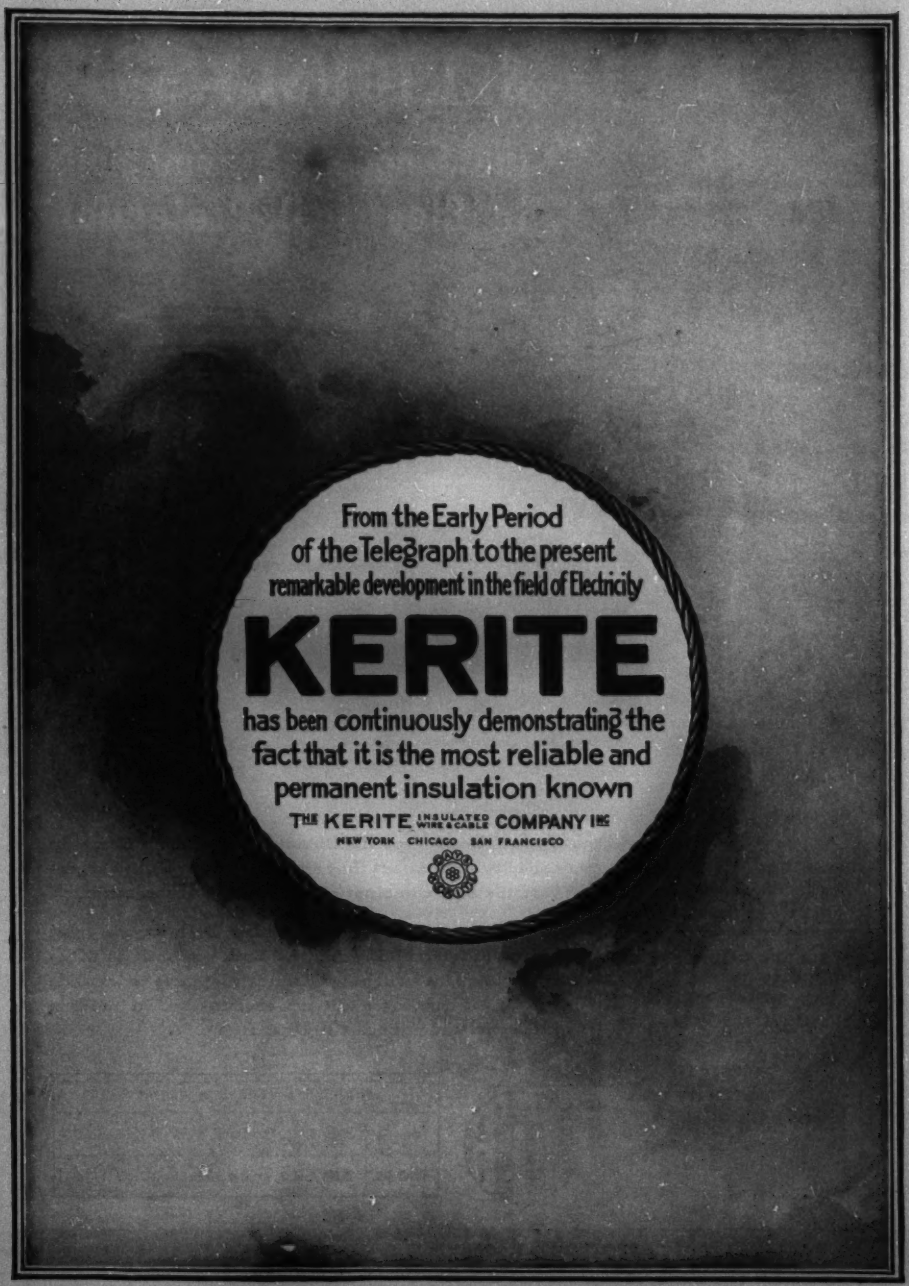


Figure 7. Photograph of HV-3 relay with glass cover removed

If it is desired to remove the restraint during a fault, it can easily be accomplished by opening any one supply lead to the restraint element. This applies single-phase voltage to all three electromagnets and the sine of θ becomes zero on all, so that there is no torque on any of them. The restraint is such that it requires ten amperes at normal voltage at the maximum torque phase angle of the directional relay to overcome the restraint torque.

In conclusion, the new polyphase inductor-loop directional relay has all the desirable characteristics inherent in the induction-disk type relay, with the additional ones of compactness, low burden, high sensitivity, and high-speed operation, which is difficult to obtain with the polyphase induction-disk type. With these outstanding advantages, it is believed that the new relay will replace the polyphase induction-disk type where formerly used and will be considered as an important advancement in relaying art.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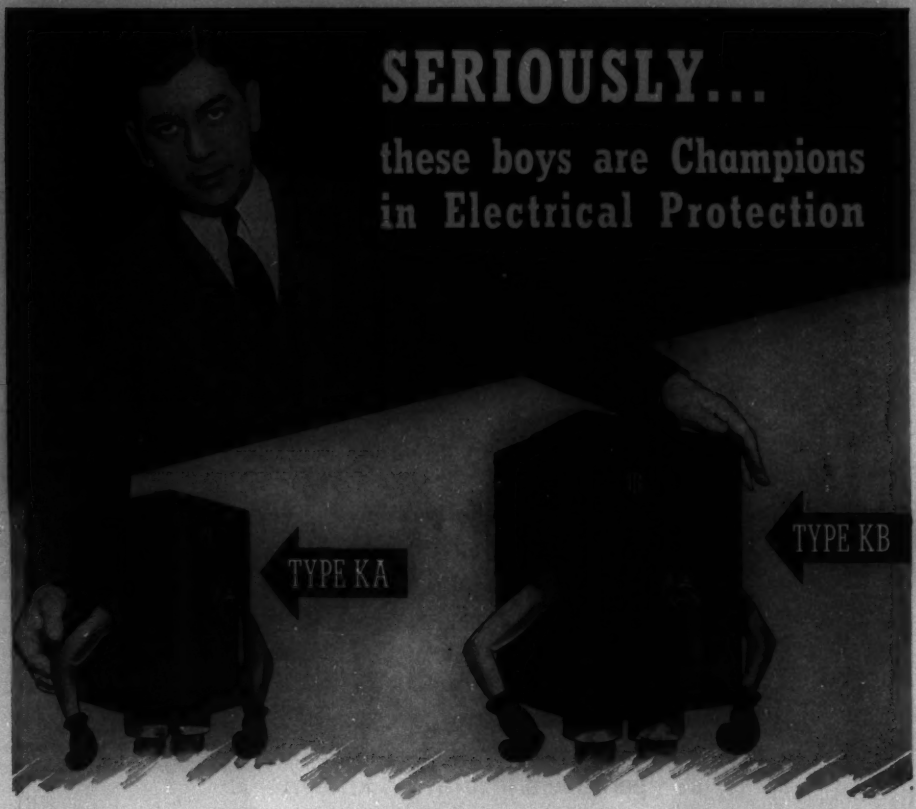

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Trade Literature

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Potentiometers.—Catalog 1101F, 32 pp. Describes photoelectrically operated potentiometers. C. J. Tagliabue Mfg. Co., Park & Nostrand Aves., Brooklyn, N. Y.

Conduit-Structural Materials.—Catalog GI-6A, 52 pp. Describes miscellaneous industrial products, including asbestos-cement electrical conduit; asbestos-ebony for panelboards and switch bases; Trancell for ceiling structures; roofing, flooring materials; refractory products; packing and gaskets. Johns-Manville, 22 East 40th St., New York.

Distribution Transformers.—Catalog 413, 16 pp. Describes a complete line of distribution transformers from 1½ to 25 kva., 2,400 to 13,200 volts; outlines the principles of design; covers insulation, porcelain enamel tanks; and the ingenious B.I. core. Data are included on the new EEI-NEMA standards according to which these transformers are constructed. Kuhlman Electric Co., Bay City, Mich.

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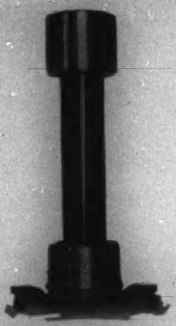

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Enclosed Motors.—A new line of totally enclosed, fan cooled motors, introduced by the Century Electric Co., St. Louis, Mo., provide necessary protection where the air is foggy with metal cutting solutions, or where there are abnormal quantities of metallic, abrasive and other dusts in the atmosphere that would ordinarily injure or clog the windings of a general purpose open motor. Cooling air is forced through the large air passages by the non-sparking fan, causing a cooler motor with cleaner air passages, which are not easily clogged. In addition to improvements in internal design, the motors have been improved in appearance with more symmetrical surfaces and finished in a smooth machine gray to blend with other manufacturers' equipment.

(Continued on page 20)

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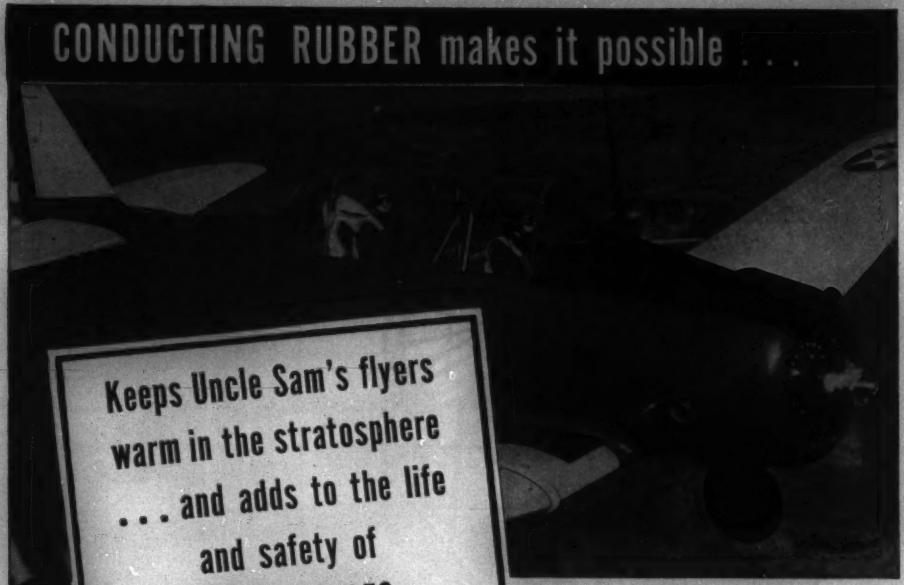

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FLEXIBLE STRIPS of conducting rubber concealed in a new undersuit heat up like wires in a toaster; keep army stratosphere flyers warm at 60° below zero.

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THESE PHOTOGRAPHS taken in our laboratory show a 15 watt bulb being lighted by the flow of current from a 110 volt plug-in, through an ordinary "dumb-bell" sample of conducting rubber. These tests indicate that a wide range of conductivity in rubber is available, and this conductivity can be varied to suit the best design of the cable.

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New Products

(*Continued from p. 18*)

Kilovoltmeter Multipliers.—The kilovoltmeter multipliers (No. 765) introduced by the Shallcross Mfg. Co., Collingdale, Pa., are resistance boxes designed to furnish a practical and inexpensive external meter multiplier for a variety of instruments for measuring potentials. The device consists of a low potential voltmeter connected with

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A-C Tachometers.—No commutator or brushes are used in this new a-c tachometer developed by the Westinghouse Electric & Mfg. Co., East Pittsburgh. The a-c voltage generated is rectified and indicated in terms of rotational or linear speeds. The indicating instrument on the left can be calibrated in revolutions per minute, feet per minute, gallons per minute, or other units depending on the application.

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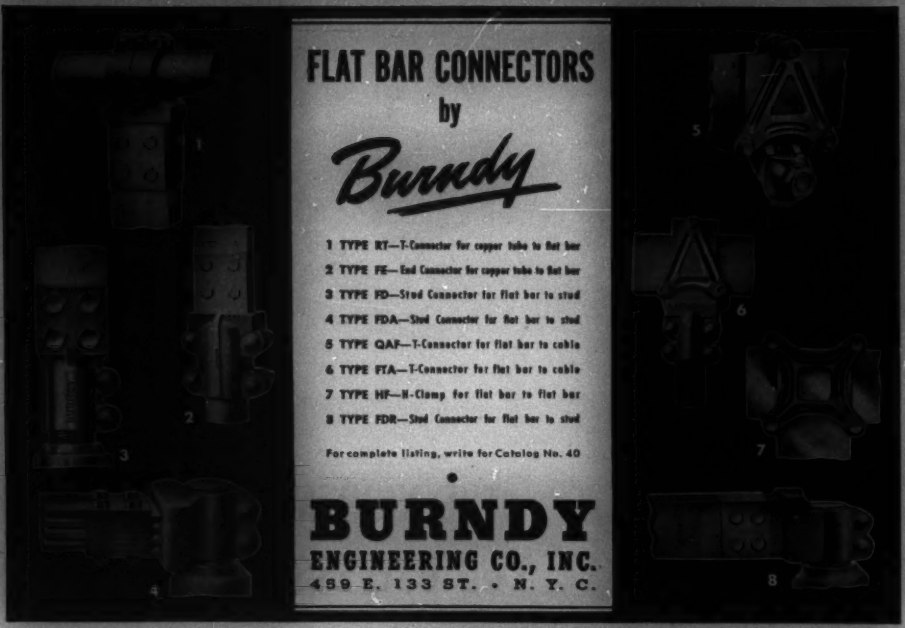
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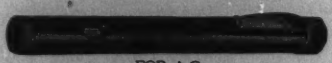

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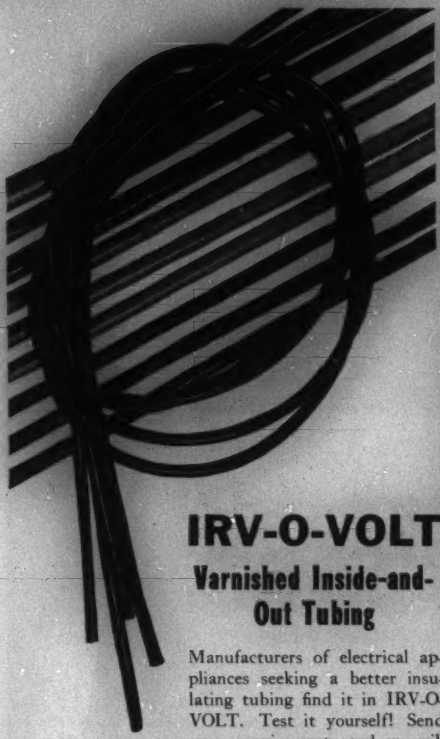

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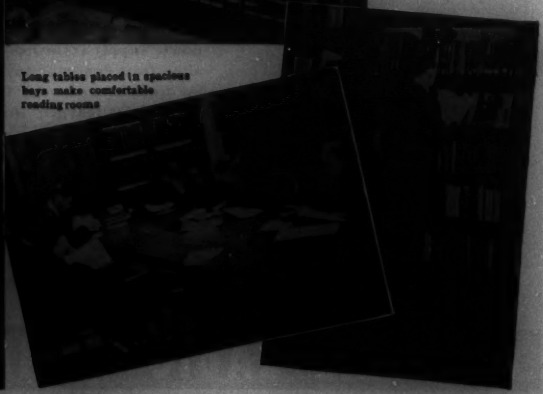

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Employment Bulletin

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MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the four offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

Men Available

B.S.E.E., Lehigh Univ; 29, married; desires pos valuation or elec pwr sales and distr; 5 yrs engg exper; now employed. Desires pos with future. Location immaterial. E-817.

B.E; 22 yrs des, supervision pwr stations, substations, switch structures, distr, investigations, economic studies, indus plants switchboards, transf stations, pwr, ltg, control, interlocking and signal systems. E-818.

E.E., univ grad; about 20 yrs exper, mostly in pwr prod and distr, desires pos preferably with large user of elec pwr or with pub util organization. E-819.

REGISTERED PROF E.E.; 39, married; 10 yrs exper maintenance engr of mech and elec eqpt in mfg plants and office bldgs. Desires pos as eqpt engr, supervision of sales. Metropolitan area preferred. E-820.

ENGR with long indus exper and specialized knowledge and exper in U.S. and foreign patents seeks connection requiring expert liaison between inventors and attorneys in radio or allied fields. E-821.

B.E.E.; 30 married; 3 yrs elec des; 4 yrs electronics research and devpmt, including indus control. Excellent exper and record. Prefer East. E-822.

SALES ENGR; 48, married; 25 yrs sales exper indus and constr elec eqpt. Specialist ltg and pwr sales. Ability train, direct, build up sales. Seeking pos where develop. E-823.

E.E.; 30, married; 8 yrs steam plant controls, accessories, des, devpmt, production. Now employed foreign. Desires pos chief engr small mfr steam plant or process controls, domestic or foreign. E-824.

EXEC ENGR, elec and mech, for managerial or staff duties, exper in steel mill engg, oprn, maintenance, process or patent devpmt, employee relations, etc. E-825.

REGISTERED PROF ENGR; 28 yrs exper des, constr, pwr houses, substations, indus plants. Exec engr large util; purchased engg eqpt foreign interest. Available short notice. E-826.

DESIGNER, E.E.; 37, married; good exper layout elec test eqpt and accessories, motors, transf, radio apparatus; also some supervision. Strongly interested in elec product devpmt, des, scheduling. Location, Greater New York. E-827.

TECHNICAL GRAD; 42, family man; 14 yrs present firm, wishes permanent change factory production. Handled up to 200 men, various machines and other details of production. Moderate salary. E-828.

S.M.E.E., M.I.T., 1933; 30, single; 7 yrs with pneumatic tool and machinery mfr, application elec and electronic methods to des problems and special tests, devpmt testg machines. Prefer East. E-829.

B.S.E.E., Univ of Kansas, 1940; 24, married; hard of hearing. Wants permanent pos in des, estimating, draftg, with chance for future. Employed. Location not important, prefer Midwest. E-830-742-Chicago.

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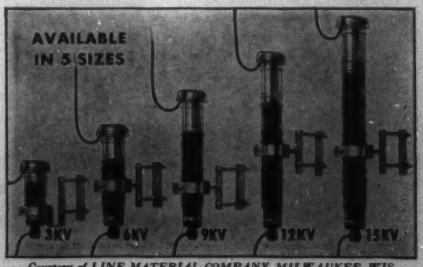

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Pyrex Insulators
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Advertised Products Index

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National Carbon Co., Inc., Cleveland, O.

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Westinghouse E. & M. Co., E. Pittsburgh

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Acme Elec. & Mfg. Co., Cuba, N. Y.
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RECOMMENDED PRACTISE FOR

Electrical Installations on Shipboard

(MARINE RULES)

Sec. No. 45 AIEE Standards With Addenda as of March 1941

THE latest edition "of Recommended Practise for Electrical Installations on Shipboard" (Marine Rules) is published as Section 45 of the AIEE Standards. The pamphlet contains 100 pages; price is $1.50 (50% discount to members of the AIEE).

These rules have been drawn up to serve as a guide for the equipment of merchant ships with electrical apparatus for lighting, signaling, communication, power and propulsion for both alternating and direct current systems. They indicate what is considered good engineering practise with reference to safety of the personnel and of the ship itself, as well as reliability and durability of the electrical apparatus.

American Institute of Electrical Engineers

33 West Thirty-Ninth Street, New York

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THAT ALL UTILITY MEN WANT TO KNOW

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KUHLMAN ELECTRIC COMPANY, BAY CITY, MICHIGAN *Kuhlman*

ALLIS-CHALMERS DRY TYPE REGULATOR OPENS NEW FIELDS IN INDOOR STATION DESIGN!

Allis-Chalmers Transformer Engineers Bring Liquidless Substations Nearer. Here Are the Facts about the New Allis-Chalmers 5/8% Step DRY TYPE Feeder Voltage Regulator . . . with Natural Air Cooling.

SIX OF 45 ALLIS-CHALMERS DRY TYPE Feeder Regulators with natural air cooling recently purchased by a large midwestern system.

1 ELIMINATES OIL from stations where oil may be considered a hazard.

2 SAVES FLOOR SPACE by outmoding costly fireproof vaults. Now you can install regulators in a line like switchgear cubicles.

3 REDUCES MAINTENANCE because there's no liquid of any kind to change or filter periodically.

4 INSPECTION IS EASIER . . . simply unlatch the front door and all working parts are exposed for a quick, easy check-up.

5 NO AIR BLAST equipment required. The Allis-Chalmers DRY TYPE Regulator has *natural* air cooling.

In addition, the Allis-Chalmers DRY TYPE Regulator includes all the engineering advancements of the popular oil-immersed 5/8% Step Feeder Voltage Regulator — closer band width settings with full-integrating control . . . quieter operation . . . a fraction of the excitation current required by older types of regulators!

For complete engineering data on the new Allis-Chalmers DRY TYPE Regulator with natural air cooling, call the district office near you. Or write for your copy of Bulletin B-6126 . . . *today!*

A 1355

These 5/8% Step Regulators Are Famous for Better Regulation at Lower Cost!
DFR — 12 to 250 kva, single phase
AFR — 20.8 to 750 kva, three phase

ALLIS-CHALMERS

AIEE Summer Convention, Toronto, Ontario, Canada, June 16–20, 1941

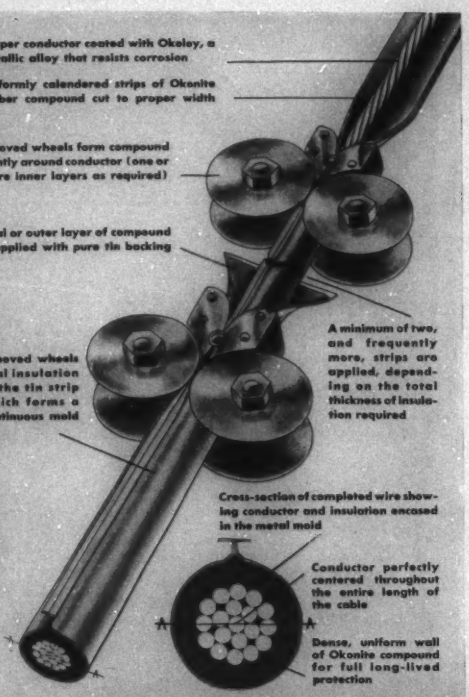
Electrical Engineering

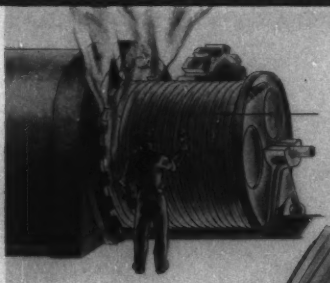
June 1941

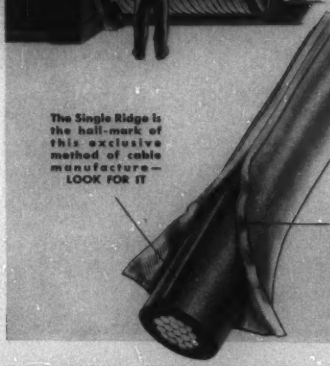
OKONITE
Insulation is Applied by This EXCLUSIVE PROCESS

Okonite wires and cables have always been distinguished for long life, exceptional electrical characteristics, high insulation density and perfect centering of conductors.

Of utmost importance to the attainment of these results is Okonite's strip-insulating process by which the insulation is wrapped around the conductor and sealed in a continuous metal mold during vulcanization. For nearly 60 years we have made Okonite insulation this way and for 60 years Okonite has been compiling unequalled records for unfailing performance under severest service conditions.


Copper conductor coated with Okolay, a metallic alloy that resists corrosion
Uniformly calendered strips of Okonite rubber compound cut to proper width
Grooved wheels form compound tightly around conductor (one or more inner layers as required)
Final or outer layer of compound is applied with pure tin backing
A minimum of two, and frequently more, strips are applied, depending on the total thickness of insulation required
Grooved wheels seal insulation in the tin strip which forms a continuous mold
Cross-section of completed wire showing conductor and insulation encased in the metal mold
Conductor perfectly centered throughout the entire length of the cable
Dense, uniform wall of Okonite compound for full long-lived protection


Vulcanization takes place under high temperature and pressure. The metal mold insures even density and heat distribution


The Single Ridge is the hall-mark of this exclusive method of cable manufacture—LOOK FOR IT
The tin mold is removed after vulcanization and the insulated conductor is ready for a series of complete electrical and mechanical tests before application of coverings

5 FOUNDATIONS OF OKONITE QUALITY

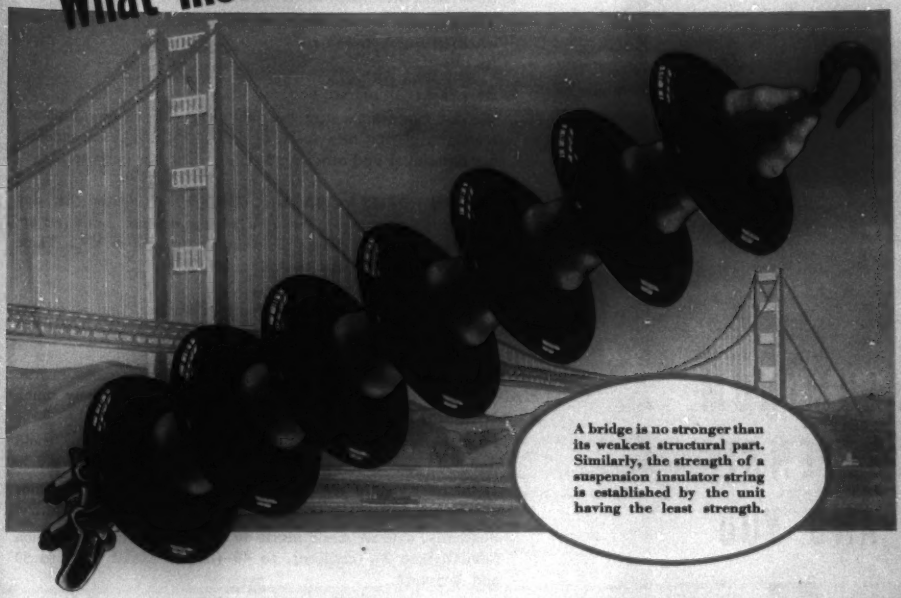
1. Made only with Up-river Fine Para rubber carefully washed and dried
2. The Okonite formula is proved by long use rather than accelerated tests
3. Conductors perfectly centered by the Okonite strip-insulating process
4. Uniformly vulcanized under pressure in a continuous metal mold
5. Thoroughly tested and inspected throughout the manufacturing process

Okonite's Okolay coating on conductors eliminates corrosion

THE OKONITE COMPANY
Passaic, New Jersey
Offices in principal cities

OKONITE Insulated Wires and Cables

What Insulator Strength Is Your Guide?


A bridge is no stronger than its weakest structural part. Similarly, the strength of a suspension insulator string is established by the unit having the least strength.

Several mechanical strength values can be determined for a group of suspension insulators—actual and probable maximums, averages and minimums, and various time-loads. But only one type of these values—MINIMUM STRENGTH—can be used as a reliable guide in selecting insulators because the weakest unit establishes the strength of an entire insulator string. This basic principle explains why so many transmission engineers are using minimums. And it reveals the vital portent of the fact that *M & E ratings of all O-B suspension insulators are now their minimum strengths.* Providing designers with dependable insulator minimum values is one important advantage of the greater strength of O-B's suspensions. Another significant benefit is that lower-rated, *lower-priced* insulators can be used for many installations since O-B recommends 50 per cent of the minimum M & E rating as the safe working load. To get these extra strong suspension insulators, noted for long life and having reliable minimum strengths equal to or greater than their M & E values—buy O-B!

Buy the Best ...Buy O-B

Ohio Brass

MANSFIELD, OHIO, U. S. A.

Canadian Ohio Brass Co., Ltd., Niagara Falls, Ont., Canada

ELECTRICAL ENGINEERING. Published monthly by the American Institute of Electrical Engineers; publication office 20th & Northampton Streets, Easton, Pa. Editorial and advertising offices, 33 West 39th Street, New York, N. Y. Subscription $12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain and Spanish colonies; $13 to Canada; $14 elsewhere; single copy $1.50. Entered as second-class matter at the Post Office, Easton, Pa., under the Act of Congress of March 3, 1879. Accepted for mailing at special postage rates provided for in Section 538, P. L. & R. Act of February 28 1925.

June 1941, Vol. 60, No. 6. Number of copies this issue 22,800.

ALUMINUM, DEFENSE, AND YOU

ALCOA

3

IT IS EASY TO UNDERSTAND ABOUT ALUMINUM AND DEFENSE

THE WHOLE THING BOILS DOWN to two simple questions:

1. **How much aluminum** are America and England going to need?
   There is only one answer: The democracies must have *all the aluminum it takes to win*, and nobody knows how much that is.
2. **How fast** is aluminum needed?
   We don't know, for sure, but just as fast as the aircraft plants, munition plants, shipyards, and the like, can be expanded to use aluminum and other materials for defense purposes.

THOSE IN AUTHORITY IN WASHINGTON are putting together, day by day, expert estimates of what all these defense industries are going to need, month by month, clear to the end of 1942. These estimates, as issued, are our book of rules.

FOR MONTHS WE HAVE BEEN, and are now, delivering aluminum for defense purposes far in excess of that called for by prior estimates.

DEFENSE IS NOW TAKING from us over 40 million pounds a month. Every American ought to have a picture of just how much aluminum that is; here it is:

Peace-time America, during the nine years from 1930-8, could find use for only 14 million pounds a month from us.

In the busy year of 1939 we had to make only 27 million pounds a month to satisfy the civilian needs of this prospering country.

Suddenly, defense alone needs 40 million a month! 14 million (civilian), to 27 (civilian), to 40 (defense) and soon to 50 and beyond!

* * * *

YOU CIVILIAN USERS of aluminum are grand people.

THE WAY YOU ARE DOING WITHOUT aluminum until producers can catch up again with civilian uses is typically American. We are sincerely grateful for your understanding.

IN THIS RECESS you are having to scramble for **RECESSITIES**—other materials which just don't fill the bill 100%, because there is no pat substitute for aluminum.

IT'S TOUGH ON YOU and it's hard on us to have to turn away temporarily from the friends and pursuits of a lifetime.

WE HAVE NOT TURNED OUR BACKS!

WE INTEND that no civilian shall have to forego the things aluminum can do best one minute longer than we can help.

ALUMINUM COMPANY OF AMERICA

The latest development in Industrial Power distribution

I.F.B.—Industrial Feeder Bus and I.P.I.—Industrial "Plug-In" Bus embody the latest improvement in the enclosed busbar system of electrical power distribution. Write for literature.

National Electric
PRODUCTS CORPORATION
Pittsburgh, Pa.

A New Wirewa

NATIONAL FOUR BY FOUR WIREWAY

4 x 4 Wirewa may be mounted direct to the wall. No projecting brackets necessary. Quick and easy to install couplings. Only two bolts to tighten. Quick access to the full length of wireway. Investigate—Write for literature.

National Electric
PRODUCTS CORPORATION
Pittsburgh, Pa.

NEP Products

"Plug-in" Strip

The new "Plug-in" Strip method of Circuit Wiring, developed by National Electric Products Corporation, Pittsburgh, Pennsylvania, provides adequate outlets every 6, 18 or 36 inches all around the entire room—literally "Outlets by the Yard."

The strip is easily installed directly on top of the baseboard or beneath the baseboard trim. "Plug-in" Strip comes in 6″, 1′, 18″, 2′, 3′, 6′ and 9′ lengths. It is finished in black and it can be quickly painted to match any color.

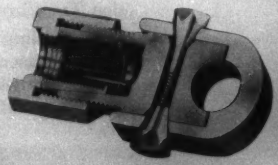
Write to National Electric Products Corporation at Pittsburgh for the booklet they have just issued on this material—adv.

Mechanical Connectors

The National Electric Products Corporation of Pittsburgh, Pennsylvania, has used the orthodox method of the wedge principle in the construction of their Gorilla Grip Connector line.

The connectors embody two types of this wedging principle—the sleeve, lock-ring and nut and the tapered bolt and nut.

The cross-section shown reveals how the wedge principle is applied.



The connectors may be purchased in handy stock or emergency sets which makes it possible to carry 125 various combinations of connectors directly to the job without back-tracking to the stock room and losing valuable time on a breakdown.

Write to the company for literature—adv.

√Check

National Products melt into the job without those losses usually incident to promiscuous buying.

SHERARDUCT
ECONOMY
XDUCT
SHERARDUCT JR.
XDUCT JR.
NEPCODUCT
A. B. C. CABLE
FLEXSTEEL CONDUIT
OVALFLEX
I. F. B.
I. P. I.
4 x 4 WIREWA
METAL MOLDING
XTENSIONDUCT
FLORDUCT
"PLUG-IN" STRIP
"CANVAS-BACK" LOOMWIRE
FITTINGS
EDGE BOXES AND COVERS
RILLA GRIP CONNECTORS
LEC" WIRES AND CABLES
INDESTRUCTO
CKETS AND WIREHOLDERS
OVALDUCT

REASONS WHY ENGINEERS CHOOSE THE NEW

1 Simplified Supports for Direct Pole Mounting Cut Installation Time. Standard Support Spacing and Bushing Location Mean Complete Interchangeability of All Sizes and Makes.

2 New, Durable, Copper-Bearing Steel Tanks. Tested Under Pressures Far Greater than Normal . . . Prevent Oil Leakage, Assure Long Life and Complete Safety.

3 New Spra-bonderizing Process . . . Plus Triple Coat Automobile Finish Give Tanks Positive Four-way Protection Against Attacks of Rust and Corrosion.

"I Like Its Six Big

You'll Like The Engineering Advancements Built Into the New Allis-Chalmers Distribution Transformer to Give You Easier Installation . . . Greater Dependability . . . Money-Saving Operation!

It's here! The transformer you helped us design — the new Allis-Chalmers EEI-NEMA Distribution Transformer!

By pooling the knowledge of hundreds of operating men all over the country, it has been possible to design a transformer that makes your specifying and buying easier . . . a simplification

ALLIS-CHALMERS DISTRIBUTION

ALLIS-CHALMERS DISTRIBUTION TRANSFORMER

4 Extra-heavy Porcelain Coordinated Bushings with Liberal Creepage Offer Maximum Reliability Under Fog, Dust, Chemical or Other Adverse Conditions.

5 Double Conductor Insulation . . . Flexible Enameled Wire . . . Plus the Added Protection of Well-Lapped Cable Paper Provide Double Safety Against Winding Failures.

6 Improved Core and Coils, Liberally Designed with No Manufacturing Short Cuts . . . Mean Extra Years of Service-free Performance Under All Types of Operating Demands.

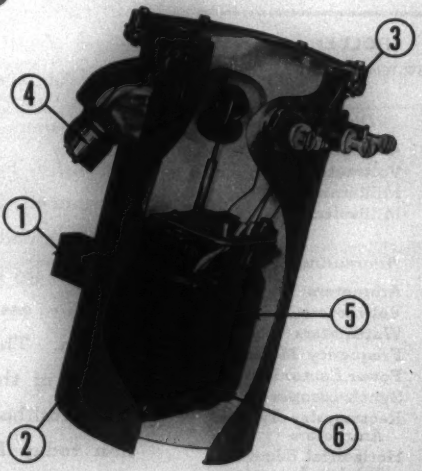
Engineering Features!"

that will undoubtedly save thousands of dollars, not only in first cost, but in operating expenses as well.

How is this done? By standardizing the location of supports and bushings, all sizes and makes are now completely interchangeable. This means you can get faster deliveries . . . easier installation. It also means fewer parts and fewer complete units for you to handle in stock.

Remember, too, Allis-Chalmers cuts no corners in its manufacturing process. Advanced engineering . . . plus the best material and skilled workmanship . . . give you built-in quality second to none.

For complete engineering information on the new Allis-Chalmers EEI-NEMA Distribution Transformer, call the district office near you. Or write for your copy of our new Bulletin B-6159. Allis-Chalmers Mfg. Co., Milwaukee, Wisconsin.



A-1382

TRANSFORMERS *Cut Operating Costs*

LOOK Behind the Dial

ROLLER-SMITH
SWITCHBOARD INSTRUMENTS

Direct Current

Ammeters
Voltmeters
Milliammeters
Millivoltmeters

Alternating Current

Ammeters
Voltmeters
Wattmeters
Frequency Meters
Power Factor Meters
Synchroscopes
Rectangular Triplex Ammeters
Horizontal Edgewise Triplex Ammeters

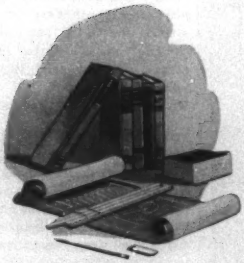
—and you'll find this Roller-Smith D.C. switchboard ammeter a sturdily built, yet highly sensitive instrument.

Its design has been balanced to give best overall performance. The tungsten steel magnet is generously proportioned. The permanent magnet moving coil mechanism is effectively damped. Sturdy bridge construction assures accurate spacing and permanent calibration. The features found in the d-c ammeter are typical of the complete Roller-Smith line of a-c and d-c switchboard instruments. Get complete information today from our nearest representative or write Roller-Smith, Bethlehem, Pennsylvania.

Electrical Measuring and Protective Apparatus

ROLLER-SMITH COMPANY BETHLEHEM, PENNA.

Switchboards • Metal Enclosed Switchgear • Electrical Instruments
Indoor and Outdoor Oil Circuit Breakers • Air Circuit Breakers



If you'll abandon all idea of what high voltage station insulators have always looked like...set out to design a unit best calculated to meet operating requirements . . . find a plant capable of producing your design with mechanical soundness . . . test it ten years on operating systems coast to coast . . . then, and only then, you'll have an insulator that offers the operating advantages characteristic of the Lapp Station Post.

Lapp

LAPP INSULATOR COMPANY, INCORPORATED • LEROY, N. Y.

PIONEERS & SPECIALISTS in ENCLOSED

"LO-X" (Low Reactance) TYPE FOR MAIN FEEDERS

End view of a three-phase section of "LO-X" Bus Duct with conductors so arranged and proportioned that magnetic field is minimized with resultant low losses. This design also permits the use of a rugged steel casing giving greatly increased mechanical strength with no sacrifice of electrical efficiency.

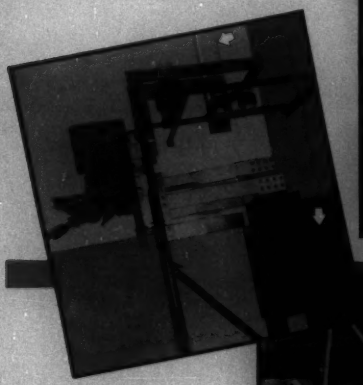
At right, Bull Dog Feeder Type BUStribution DUCT used as a riser from outside transformers. Loads are tapped off at each floor and distributed through panelboards or Bull Dog "Plug-in" Type BUStribution DUCT.

"LO-X," the latest addition to Bull Dog's Flexible Electrical Distribution Systems, is the most efficient design available in current-carrying conductive systems for heavy currents. Here for the first time is a busbar system which assures the industrial user of ample voltage at the point of application, wherever and whenever needed.

"LO-X" is designed especially for the most efficient distribution of current in the conductors, and for the most effective heat dissipation characteristics. The result is greater current-carrying ability, lower operating temperatures, and less voltage drop due to reactance.

"LO-X" may be used alone, or it may be combined with Bull Dog's "Plug-in" Type BUStribution DUCT, and associated fittings. Whatever the installation, "LO-X" affords a high load capacity, better voltage regulation, greatly reduced line drop, and consequently more efficient and uniform operation.

"LO-X" is available in from 500 to 4,000 amp. capacity, 600 volts or less, single phase, three phase, and three phase 4 wire.



Note in the illustration above how the 2,000-ampere "LO-X" BUStribution DUCT leaves the Transformer Room, thence through Main Breaker in Switch Room, and out through the wall into the factory where, as shown at the right, it extends the entire width and depth of the plant. Cable Tap Boxes as shown in the illustration at right may be located at ten-foot intervals along the DUCT.

MANUFACTURERS OF VACU-BREAK SAFETY SWITCHES, CIRCUIT MASTER AND

BUSBAR DISTRIBUTION SYSTEMS

"PLUG-IN" TYPE with Outlets for Branch Circuit Plugs

Bull Dog "Plug-in" Type BUStribution DUCT is widely used not only for branch runs from the "Feeder" Type DUCT, but for complete specialized installations. Its standard ten-foot sections, with ten outlet openings to each section offer the widest latitude in machine arrangement and flexibility.

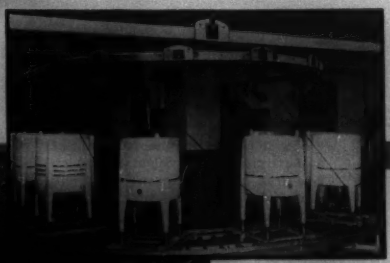
The "Plug-in" line includes every necessary type of associated fitting—elbows, tees, and crosses—together with a wide variety of Branch Circuit Plugs, Circuit Breaker Plugs, Bus Swing Plugs, etc. "Plug-in" Type BUStribution DUCT is available with either two or three conductors, in capacities from 125 to 1,500 amperes, 600 volts or less.

For complete information on all Bull Dog Busbar Systems — BUStribution DUCT, Universal and Industrial Trol-E-Duct — send for complete descriptive bulletins, or better yet, ask to have a Bull Dog sales engineer call on you.

BULL DOG
ELECTRIC PRODUCTS CO.
DETROIT, MICHIGAN
•
Bull Dog Electric Products of Canada, Ltd., Toronto, Ontario

The illustration above shows how conveniently a whole battery of machines may be connected to "Plug-in" BUStribution DUCT. And machine arrangement may be quickly and easily altered at any time, with no delays for rewiring.

An installation of Bull Dog Universal Trol-E-Duct for flexible lighting paralleling the BUStribution DUCT system. Individual lights attached to movable trolleys or twist-out plugs in the duct provide illumination exactly where needed.



Bull Dog Industrial Trol-E-Duct as shown above in the illustration of a washing machine assembly line, provides mobile current and suspension support for portable tools. Industrial Trol-E-Duct is also widely used for monorail hoist and crane systems.

★

Typical Installation of Bull Dog "Plug-in" Type BUStribution DUCT with Circuit Protective Plugs and Associated Fittings

Vacu-Break Bus Plugs

Plug-in Type BUStribution DUCT

Edgewise Tee

Edgewise Elbow

Flatwise Elbow

Short runs of conduit to motors

Fusible Plug-in Branch Run Adaptor

SAF-T-FUSE PANELBOARDS, SWITCHBOARDS, DUCT SYSTEMS—FOR LIGHT AND POWER

In the field of Telephony—whether wire or radio—wherever direct current is required from an A.C. source, I. T. & T. Selenium Rectifiers meet the exacting requirements of the art of speech transmission.

The Selenium Rectifier is a compact and extremely light weight unit which requires no maintenance and has practically unlimited life. The outstanding features in its application to Telephony are: high efficiency of rectification . . . extremely low back leak . . . high permissible ambient temperatures . . . flexibility of voltage and current output for test equipment.

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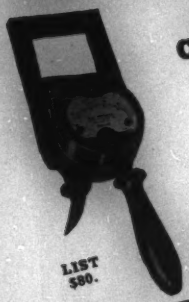
Consulting engineering services available for specific requirements.
Address Technical Department for descriptive bulletin.

INTERNATIONAL TELEPHONE DEVELOPMENT CO., INC.
67 Broad Street, New York, N. Y.

Attend the A.I.E.E. Summer Convention • Toronto • Canada • June 16-20 •

DELIVERIES—
NOT PROMISES!

LOW COST CLIPON AMMETER



LIST $80.

..Perfect Balance
..Light Weight
..Completely Insulated Jaws
..±2% Accuracy

ALSO MULTI RANGE CLIPON AMMETER

DUAL RANGE 0-100/500 AMPS

..Large 2¼" Square Opening
..Long Open Scale
..50 Scale Divisions
..10 Years' Proven Service

0-10/25/100/250/1000 AMPS.
LIST $120.

PHASE ROTATION INDICATOR

..Instant Indication of Phase Rotation
..110/550 Volts
..2½" Portable Pocket Model

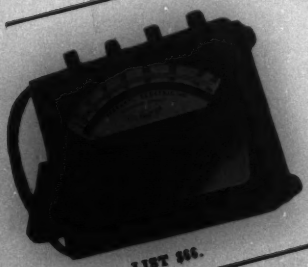
LOW COST

..Complete with Heavy Insulated Leads
..Heavy Clips with Rubber Guards
..Also Flush and Surface Types

LIGHT WEIGHT

LIST $60.

NEW HIGH ACCURACY PORTABLE VOLTMETER



LIST $66.

..0-150/300/750 Volts
..Long 5¼" Scale
..½ of 1% Accuracy
..AC-DC
..Hand Calibrated Mirror Scale
..150 Scale Divisions

MADE IN U.S.A.

..Frequency 15-135 cps.
..Hinged Cover with Leather Carrying Handle
..Light Weight—Robust Construction
..Conforms to A.I.E.E. and N.E.M.A. Specifications

NO DELAY

All Instruments Available Immediately from Stock

We can also give *immediate* deliveries on your requirements for Special Transformers, etc., etc.

FERRANTI ELECTRIC, INC.
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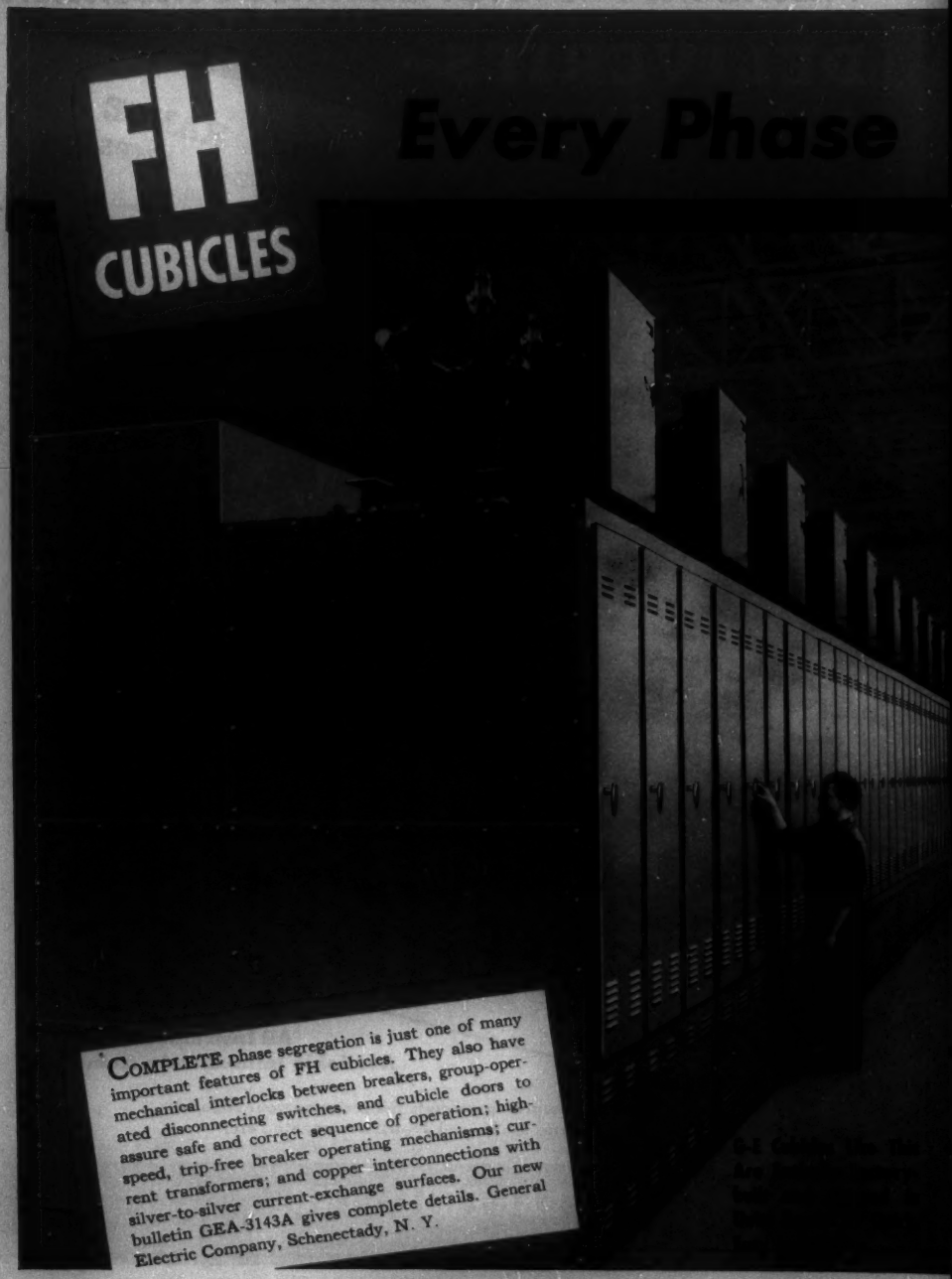
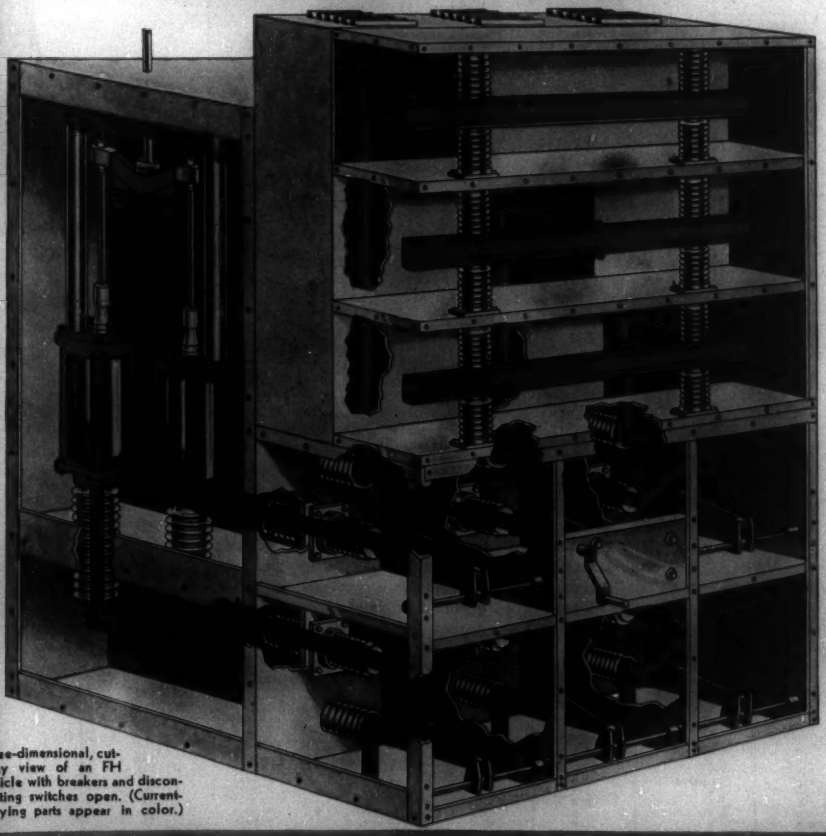

FH
CUBICLES
Every Phase
COMPLETE phase segregation is just one of many important features of FH cubicles. They also have mechanical interlocks between breakers, group-operated disconnecting switches, and cubicle doors to assure safe and correct sequence of operation; high-speed, trip-free breaker operating mechanisms; current transformers; and copper interconnections with silver-to-silver current-exchange surfaces. Our new bulletin GEA-3143A gives complete details. General Electric Company, Schenectady, N. Y.

Is Wrapped in Steel

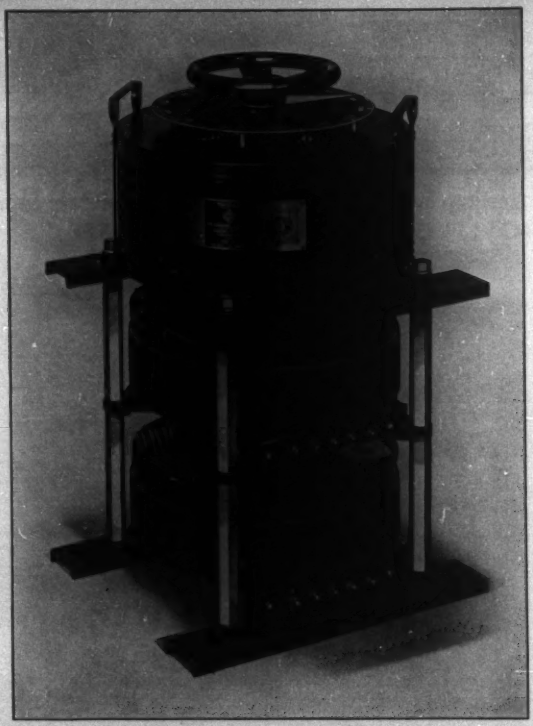
Breakers, Disconnecting Switches, and Buses Are Completely Segregated
NO LIVE PARTS ARE EXPOSED



Three-dimensional, cut-away view of an FH cubicle with breakers and disconnecting switches open. (Current-carrying parts appear in color.)

GENERAL ELECTRIC

HIGH POWER VARIACS



FOR USE WITH 2- and 3-phase loads, the ganged assemblies of VARIACS offer convenient, efficient, flexible and smooth volume control. Ganged units will handle really high power with all of the advantages found in the single units so widely used throughout the electrical utilities field.

The VARIAC, the original, continuously-adjustable autotransformer, has many advantages over any other manually operated control. Its regulation is excellent; it provides absolutely stepless control of any alternating current up to its full load rating; its efficiency is high; dials are calibrated in output voltage; it will supply output voltages 15% above line voltage; and all VARIACS are conservatively rated.

Specifications for 2- and 3-Phase Variac Combinations

INPUT		OUTPUT				
		KVA				
3-Phase Line Voltage	Circuit	At Input Voltage	At Max. Voltage	3-Phase Line Voltage	Type of Assembly	Price
230	Open Δ	3.6	4.2	0–270	100-RG2	$ 85.00
230	Y	3.6	3.6	0–460*	100-RG3	130.00
230	Y	7.2	7.0	0–270	100-QG3	130.00
230	Open Δ	12.5	9.3	0–270	50-BG2	225.00
230	Y	12.5	8.0	0–460*	50-BG3	335.00
230	Y	18.0	17.5	0–270	50-AG3	335.00
460	Y	7.2	7.2	0–460	100-RG3	130.00
460	Y	25.0	25.0	0–460	50-BG3	335.00

* Open-circuit voltage—regulation is poor for this connection.

WRITE FOR THE *NEW* VARIAC BULLETIN 706

GENERAL RADIO COMPANY

Cambridge, Massachusetts

Branches in New York and Los Angeles

MANUFACTURERS of PRECISION ELECTRICAL LABORATORY APPARATUS